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FLOOD HAZARD AND ITS IMPACT ON THE RESILIENCE OF CITIES:
An Accessibility-Based Approach to Amenities in the City of Gothenburg, Sweden

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ABSTRACT
In the wake of climate change and its impact on increasing the number and intensity of floods, adaptability of cities to and resistance against the flood hazard is critical to retain functionality of the cities. Vulnerability of urban infrastructure and its resilience to flooding from different points of view have been important and worth investigating for experts in different fields of science. Flood hazards as physical phenomena are influenced by form of the cities and thus the magnitude of their impacts can be intensified by urban infrastructures such as street networks and buildings (Bacchin et. al, 2011). In this paper, we aim to develop a method to assess the resilience of a river city (the city of Gothenburg in Sweden), which is prone to flood events, against such disturbances and find out how the city reacts to river floods and to what extent the city retains its accessibility to essential amenities after a flood occurs. To do so, collecting required data; we, firstly, simulate flood inundation with two different return periods (50 and 1000 years) and then the impact areas overlay on the street networks. Evaluating the resilience of the city, syntactic properties of the street networks before and after flooding are measured at different scales. Additionally, accessibility and the minimum distance of the street networks to essential amenities such as healthcare centers, schools and commercial centers, at a medium distance (3 Km) is examined. The results show that flooding influences the city configuration at global scale more than the local scale based on comparison of syntactic properties before and after flooding. However, the results of accessibility and the minimum distance show that the impact of flooding on the functionality of the city is more limited to the riparian areas and the city is not affected globally.

KEYWORDS
Flood inundation, Resilience, Space syntax, GIS, Accessibility
1. INTRODUCTION

“Flood” is defined as a great overflow of water which especially submerges normally dry lands. Based on statistics from Centre for research on the epidemiology of disasters (CRED, 2015) in the period 1994-2013 floods were the most frequent type of disasters and accounted 43 percent of all disasters and affected 55 percent of total population of the world during past two decades. When the flood plain includes the urbanized areas, such flooding has great impacts on both population and infrastructures and therefore, flood risk management in urban areas plays an essential role in preventing or reducing the impacts of flooding (Tucci, 2007).

In contrast to flood modelling and flood simulation which have a long history, urban resilience against flood hazard is still under development due to the complexity of the urban systems and urban drainage systems (Bacchin et al., 2011). It has been proven that urban forms and urbanization patterns are in close relationships and interaction with natural phenomena and the balance between them might break or disrupt with changing or damaging the physical structure of the cities (Herold et al., 2003; Alberti, 2009; Hillier and Hanson, 1984; Hillier et al., 2007).

In recent years, space syntax research and syntactic properties of the city combined with resilience concept have proposed different methods in assessment and reduction of the disaster risks which cover a range of possibilities from theory to practice at different scale of built environment from building to urban scales (Authors, 2017; Koch and Miranda, 2013; Carpenter, 2013; Cutini, 2013). Gil and Steinbach (2008) use properties of the road network such as connectivity, closeness and betweenness to show indirect effect of flood hazard on transport and socio-economic situations in London. In their paper areas of impact due to the level of separation from the rest of the city making islands, peninsula and peripheral areas and the degree of accessibility to the rest of the city were assessed. Carpenter (2013) used temporal data from before and after the Hurricane Katrina in 2005 and conducted syntactic properties on the street networks to identify specific syntactic and environmental parameters that had positive influences on the resilience of the city.

Flood hazards and river flooding as physical phenomena are influenced by the form of the cities and thus the magnitude of their impacts on urban infrastructures and human life can be intensified by urban infrastructures such as road networks and buildings (Bacchin et al., 2011). As such, one of the main spatial footprints of the flood impact is on the accessibility of the city (road networks for example) to different and essential amenities during the flood events. Comparing the accessibility to amenities before and after a flood event can provide important information about the adaptability of cities to flooding and resistance against the damages caused by flood hazard; an important issue that can be of interest for city planners and designers.

In this research, we aim to measure the accessibility of the road network to amenities in the city before and after flood events and compare the results to illustrate if and how the city reacts to flood hazards and to what extent the city retains its functionality against such disturbance.

In this way, we firstly use available data of the city of Gothenburg trying to simulate flood risk with different return periods and represent the affected area of the city by different floods. Finding the most vulnerable area of the city in terms of integration values and the effect of flooding on the accessibility to different facilities offered by city is also of interest in this paper.

2. DATASETS AND METHODS

Although Sweden has been less destructed by floods, the location in the estuary of Göta River in the coast of Kattegat puts Gothenburg at high risk of rising water level in both sea and in the river causing in flooding in the city. Following a global trend, the rate of flooding in Gothenburg is increasing in recent years (Filipova et al., 2012; Herbring and Landenmark, 2011). Thus, measuring and estimating the flood risk, mapping and assessing potential damage and economical loss is not only of interest for researchers but are critical for city planners and other societies of the city dealing with flood hazard and city infrastructures (Fakta om Göta älvs, 2015). Gothenburg with a population of 540,000 is the second largest city in Sweden after the
capital Stockholm (SCB, 2010, www.scb.se). Figure 1 shows a zoomed part of the city including main bridges on the river and the flow of Göta River. In this research, we limit the study area to that part of the river located inside the city (municipality border) and flood simulation and its potential impacts on the structure of the city are investigated in such area. Data required for this paper is obtained from the following sources:

- Digital elevation model (DEM) with a resolution of 2m which covers the whole study area provided by Lantmäteriet (downloaded from https://www.mapslu.se).
- Urban road network or road centre line of Gothenburg derived from open street map (OSM, downloaded from https://www.geofabrik.de/).
- Urban amenities including the location of commercial centres, healthcare centres, pre and primary schools collected from a project called “Dela[d]Stad” (Legeby et al., 2015) funded by Boverket/MISTRA Urban Futures.
- Hydrological data and measurements of the river flows for a period of 15 years collected from SMHI (http://vattenwebb.smhi.se/modelarea/)

2.1 RESILIENCE AND THE WAY WE MEASURE IT

The term resilience was coined in ecology by Holling (1973, p.14) defined as “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables” is a fashionable term for researchers and authorities involved in disaster management. The main difficulties occur when efforts are devoted to formulate the concept in order to take the term out of a purely abstract and general form -applied interchangeably for sustainability- and advance it toward a specific characteristic in a measurable and functional form (Abshirini and Koch, 2017; Lhomme et al., 2010, Folke 2006). However, there are common definitions of resilience in urban planning and disaster management. Wilbanks (2007) defined urban resilience as “capability to prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to public safety and health, the economy, and security” and Lhomme et al. (2011) defined it as “the ability of a city to operate in a degraded mode (absorption capacity) and to recover its
functions, despite the fact that some urban components are disrupted”. UNSIDR (2009) defined resilience in disaster management as “the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions.” In this view, as Carpenter et al. (2001) noticed the main questions are resilience of what or resilience to what rather than the terminology itself.

Dating back particularly to the 9th international symposium of space syntax, the concept of resilience and the way to measure it in space syntax has recently been discussed in different research, proposing different methods for evaluating the resilience of a city based on comparing syntactic properties of its road network before and after a disturbance. Shedding some light on previous works, some of them are pointed out in this literature. As an example, investigating the influence of flood risk on the city of Turin, Esposito and De Pinto (2015) took advantage of angular segments properties at global and local radii and conducted a principal component analysis to compare the spatial configuration of the city before and after the flood event. Since the comparison of spatial properties before and after the flood showed very limited changes, they considered the city resilient against the flood disaster. In a recent work, Abshirini and Koch (2017) developed a method, firstly introduced by Koch and Miranda (2013) for the building scale, to be executable on the larger architectural scale like cities. They defined two measures derived from syntactic properties called similarity and sameness. Grounded in foreground network (Abshirini and Koch, 2017), similarity measures the extent of change in the size of foreground network before and after a disturbance and sameness measures the percentage of foreground network which remains the same after a disturbance by comparing the location of segments forming the foreground network before and after a disturbance.

According to the nature of flood hazard, one of the subjects highly affected by a flood is the ease with people while access amenities in a city, called accessibility. In this research, we try to measure the impact of flood on the accessibility to essential amenities. It is worth mentioning that such effect is mostly classified as indirect impacts of flood, addressing the areas not inundated though flooding. In this view, public services, hospitals and healthcare centres, emergency services, food shops, water supplies and importantly road networks as the main connectors of such services, which is spatially located in or around the flooded area, are also vulnerable to flood (Douglas et al., 2010; Stålhult and Andersson, 2014).

Therefore, evaluating the road accessibility to such amenities and comparing the results with the accessibility after a flood occurs can help understand the indirect impacts of the flood. In a recent work, Green et al, (2017) integrating flood modelling with network analysis tried to evaluate the impact of flood on the accessibility of emergency responders to the city district in Leicester, UK. The method they developed was to measure and compare the rescue time via road networks in normal situation and during the flood events. The results showed that 10 minutes rescue time with a full coverage during non-flood condition decreased by 66.5, 39.8 and 26.2 percent for the floods with intervals of 20, 100 and 1000 years respectively. In a similar work, Coles et al, (2017) tried to model emergency accessibility during flood events in York, UK using numerical modelling of flood and overlaying the flooded areas on the road networks to detect inaccessible areas according to a 10 minutes rescue coverage. The results showed the impact of flood events by both reducing in the coverage area and increasing in rescue time.

In this research, we evaluate the resilience of the city based on two different properties: syntactic properties of the street networks including integration and choice values and accessibility value measured based on metric distance (3Km) and minimum distance to amenities. Accessibility is defined as the number of amenities located within a distance from each segment of the street networks and minimum distance is the shortest path to an amenity from a segment measured in metric unit. Comparing syntactic properties and accessibility measures before and after each disturbance reveals the impact of such disturbance on the city configuration and accessibility of street networks, providing quantitative measures to evaluate the resilience of the city against flooding. In this view, what makes this research different from the above-mentioned works is that we measure the accessibility to different amenities and do not limit the analysis to one specific amenity. Furthermore, in this research, we measures accessibility of the entire network
to amenities and do not confine the analysis to few centres or limited area, resulting in a more comparative view of the city functionality and city adaptability against the flood event.

3. RESULTS

The results gained from different analyses are discussed in this section for 2 different situations: Flood inundation with a return period of 50 years and flood inundation with a return period of 1000 years which hereafter called flood L (low) and flood H (high) respectively, due to the degree of their impacts. The flood simulation process was grounded in a GIS platform using tools developed by ESRI and HEC-RAS. The delineation of the watershed and stream network and geometric data including cross sections, flow direction, bank areas and Manning coefficient are prepared and used as inputs to HEC-RAS to simulate potential water flow or flooding according to different return period of 50 and 1000 years (see Demir and Kisi, 2016; Khattak et al, 2016; Goodell and Warren, 2006 for more information). In the end, the results of flood simulation were overlaid on the road network as well as amenities maps to identify the areas of impact. The accessibility analysis is done by PST (Place Syntax Tool) developed by Ståhle et al. (2005) for MapInfo software.

The section starts with the comparison between syntactic properties (choice and integration values) of the city at different scales from local to global to show how such values changes before and after flooding. Then, it represents the accessibility to different amenities before and after the flood events and evaluates the resilience of the city regarding the flood impacts. It should be mentioned that due to the importance of flood H and higher effects of flood H on accessibility, thus the impacts of flood H is more analysed compared to flood L (Table 1).

<table>
<thead>
<tr>
<th>Syntactic Properties</th>
<th>Geometric Distance (Degree)</th>
<th>Compared to original situation for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalised Angular Integration (NAIN)</td>
<td>180, 270, 360, 450, 900, 1200, 1800, 3600, 4500</td>
<td>Flood L &amp; Flood H</td>
</tr>
<tr>
<td>Normalised Angular Choice (NACH)</td>
<td>180, 270, 360, 450, 900, 1200, 1800, 3600, 4500</td>
<td>Flood L &amp; Flood H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessibility</th>
<th>Metric Distance (Km)</th>
<th>Compared to original situation for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>3</td>
<td>Flood L &amp; Flood H</td>
</tr>
<tr>
<td>Healthcare</td>
<td>3</td>
<td>Flood L &amp; Flood H</td>
</tr>
<tr>
<td>Preschool</td>
<td>3</td>
<td>Flood H</td>
</tr>
<tr>
<td>Primary school</td>
<td>3</td>
<td>Flood H</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum Distance</th>
<th>Metric Distance (m)</th>
<th>Compared to original situation for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>In Meter</td>
<td>Flood H</td>
</tr>
<tr>
<td>Healthcare</td>
<td>In Meter</td>
<td>Flood H</td>
</tr>
<tr>
<td>Preschool</td>
<td>In Meter</td>
<td>Flood H</td>
</tr>
<tr>
<td>Primary school</td>
<td>In Meter</td>
<td>Flood H</td>
</tr>
</tbody>
</table>

Table 1 - different analyses conducted on the street networks discussed in this research.
Before going to the main discussion, in Figure 2, we show the areas and the segments which inundated through different flooding.

![Figure 2 - segments inundated by flood H (upper) and flood L (lower). The number of inundated segments comes in parentheses.]

**3.1 SYNTACTIC PROPERTIES**

Figure 3 shows the normalized angular choice (NACH) and normalized angular integration (NAIN) values at the global scale (angular analysis in 4500 degrees is considered as global). As an interesting point it can be seen that after flood L and flood H, maximum NACH values are a bit increased while it is obvious that the segments with the high values (coloured in red) are almost disappeared from the centre and around the river. This situation in NAIN values shows that after flood L and flood H, the maximum values are dramatically reduced and segments
with high values are intensely disappeared from the city centre and around the river. Having a better understanding of changes after flooding at different scales, Figure 4 and Figure 5 show differences in mean and maximum values of integration and choice properties compared to original properties (before flooding) at different geometric scales (different degrees).

To be consistent with the results, in all cases the values of original situation is subtracted from the flood situations. As a general trend, the differences in the mean value for flood L and flood H and for both choice and integration measures are positive, meaning that the mean values reduces after disturbances and differences increase as the scale of angular analyses increase toward the global scale. As seen in Figures 4, the differences generally increase for the mean NACH, although differences at the middle scales (900 and 1200 degrees) slightly reduce. Such pattern is not seen for NAIN measure as it shows steady increase in the differences while increasing the scale of analysis. In this view, the maximum difference for NACH measure is seen in 4500 degrees for flood (H) which is equal to 0.025 followed by 0.018 for flood (L). The maximum difference in the mean NAIN value is also seen in 4500 degrees for flood (H) equal to 0.084 which followed by 0.067 and 0.50 for the flood (L) accordingly. The results show that NAIN measures compared to NACH measures are more affected by disturbances.
Figure 5 shows differences for the maximum values of NAIN and NACH properties on diagrams. As seen, differences for NAIN measure follow the same trend as the mean value. The maximum difference is seen in 4500 degrees for situations, where it is 0.144 for flood (H) and 0.124 for flood (L). However, differences for NACH measure follow a complex trend and do not show an explicit trend. In this case, the differences are zero at the local scales (180, 270, 360 and 450 degrees) for all conditions while taking negative values at the middle scales (900 and 1200 degrees) for flood H while flood L is still zero until 1800 degrees. However, at the global scales (3600 and 4500 degrees) sea-level rise is positive, while both flood H and flood L show positive values in 1800 and 3600 degrees and negative values in 4500 degrees. As a conclusion for this part, we can state that disturbances such as flood inundations influence syntactic properties of the city structure by generally decreasing the values for the integration and choice properties, less at the local scales and more at the global scales, both for the mean and the maximum values.

3.2 ACCESSIBILITY TO AMENITIES

3.2.1 COMMERCIALS

In Figure 6 the percentage of difference between original situation and flood situations is shown. As seen, the area of difference for flood L is distributed asymmetrically to both sides of the river but centralised in the middle of the river. As an interesting point, the riparian areas in the southern side are less affected by flood L compared to the northern side. The most affected area in the southern side occurs along the sub-stream river (coloured in red). The condition for flood H is different, as the riparian areas in both sides are highly affected and the total area (number of segments) of influence is increased (Table 2).
However, the asymmetrical distribution of accessibility differentiation is yet seen and same as flood L, the area along the sub-stream river is highly affected as the area of influence is extended to the both sides of the sub-stream.

<table>
<thead>
<tr>
<th>Amenities</th>
<th>Flood L</th>
<th>Flood H</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Accessibility</td>
<td>Accessibility</td>
</tr>
<tr>
<td>Commercial</td>
<td>20780</td>
<td>23603</td>
</tr>
<tr>
<td>Healthcare</td>
<td>12060</td>
<td>14994</td>
</tr>
<tr>
<td>Preschool</td>
<td>14453</td>
<td></td>
</tr>
<tr>
<td>Primary school</td>
<td>10336</td>
<td></td>
</tr>
<tr>
<td>Total number of segments: 100556</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 - Number of segments of which accessibility is affected (only indirect impacts) after flood L and flood H for different amenities separately.

### 3.2.2 HEALTHCARE CENTERS

In Figure 7, the difference in accessibility to healthcare centres in two situations, flood L and flood H is illustrated. Same as accessibility to commercial centres for flood L, distribution of influenced areas is asymmetrical and non-equal as it is more extended in the southern part of the river alongside the sub-stream. Eastern part of the sub-stream is more affected but less distributed while the western part, contrariwise, is more distributed and less affected.

The condition in the northern part of the river shows that riparian areas spatially close to the bridge is more influenced by flood L, but generally, the northern side is less affected than the southern side. Looking at Figure 7, three different distributions are recognised. A more affected but less distributed area is located in the eastern part of the sub-stream, a low to mid affected but more distributed in the western part of the sub-stream and a low affected and less distributed area located in the northern part of the main river. Riparian areas in the southern side of the river are generally more affected than areas in the northern side of the river. Table 2 shows the number of segments which their accessibility changes (reduces) after flooding.
3.2.3 PRESCHOOLS AND PRIMARY SCHOOLS

In Figure 8, we investigate the accessibility to preschools and primary schools only after flood H due to the more importance and bigger effects that flood H causes. Despite similar trend and asymmetrical distribution to the other amenities in general, there are yet differences in their distributions. As seen, affected areas, when analysing preschools, are totally more distributed compared with primary school. This can be seen on both sides of the river. However, the extent of changes shows a higher impact of flood H on the accessibility to primary schools than to preschools, represented by more areas highlighted in red for primary schools. Table 2 also shows that the number of segments with a reduced accessibility for preschools is higher than for primary schools. Furthermore, accessibility of riparian areas to preschools is less affected (green in Figure 8) than similar areas for primary schools (yellow in Figure 8).

![Figure 8 - Accessibility difference to preschools and primary schools only after flood H: grey colour = no differences, green and yellow colours = low differences, orange and red colours = high differences.](image)

3. 3 MINIMUM DISTANCE TO AMENITIES

One of the important parameters that reveal the impact of flood events on the city structure is changes in the minimum distance to amenities. In this view, areas with a higher impact usually show increases in the distance to the closest amenity. In Figure 9, the percentage of change (increase) in the minimum distance to different amenities is illustrated separately. It should be noted that due to the very little change in the minimum distance after flood L, we illustrate the results only for flood H.
As a general trend in Figure 9, the effect of flood H on the minimum distance to amenities is low and mostly limited to few segments in the riparian areas of the main river, while their distributions are not symmetric and do not follow the direction of main river. Based on Figure 9 and Table 3, we can find that the minimum distance to healthcare centres is more affected by flood H compared with the minimum distance to the other amenities, as it is extended to the area around the sub-stream. As such, commercial centres are the least affected amenities among all. Additionally, as a different tendency between the preschools and primary schools, we can say that the minimum distance for primary schools is more affected by flood H spatially on the northern side of the river.

![Figure 9 - Changes (increase) in the minimum distance to different amenities after flood H. Grey colour = no differences, green and yellow colours = low differences, orange and red colours = high differences.](image)

<table>
<thead>
<tr>
<th>Amenities</th>
<th>Flood L Accessibility</th>
<th>Flood H Accessibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>737</td>
<td>547</td>
</tr>
<tr>
<td>Healthcare</td>
<td>2748</td>
<td>3788</td>
</tr>
<tr>
<td>Preschool</td>
<td>818</td>
<td>818</td>
</tr>
<tr>
<td>Primary school</td>
<td>1205</td>
<td>1205</td>
</tr>
<tr>
<td><strong>Total number of segments:</strong> 100556</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 - Number of segments of which minimum distance is affected (only indirect impacts) after flood L and flood H for different amenities separately.

In the end, as a possible explanation to the observed trends in the minimum distance to different amenities and that the minimum distance is not highly affected by flood events, we can say that the reason seems to be related to the distribution of the amenities themselves within the city (Figure 10). Such asymmetrical distribution of amenities along with the small number of inundated amenities after flooding (Table 4), compared to the total number of amenities, can be resulted in the small changes in the minimum distance of segments to the amenities.
FLOOD HAZARD AND ITS IMPACT ON THE RESILIENCE OF CITIES: An Accessibility-Based Approach to Amenities in the City of Gothenburg, Sweden

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Removed by flood L</th>
<th>Removed by flood H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segments</td>
<td>100556</td>
<td>2188</td>
<td>6680</td>
</tr>
<tr>
<td>Commercial</td>
<td>4612</td>
<td>176</td>
<td>1329</td>
</tr>
<tr>
<td>Healthcare</td>
<td>147</td>
<td>5</td>
<td>28</td>
</tr>
<tr>
<td>Preschool</td>
<td>566</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>Primary school</td>
<td>180</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 4 - Number of segments and amenities which are inundated by floods

Furthermore, as an explanation to the fact that the southern side of the river is more affected after flooding we can add that, besides the asymmetrical distribution of amenities in the city, distribution of street networks or density of street networks, existence of the sub-streams in the southern part of the river (Figure 1) which affect the accessibility and differences in the natural topography of different parts of the city might be the other reasons, causing the southern part of the river shows the greater impacts after flooding.

Figure 10 - Unequal distribution of different amenities in the city
4. CONCLUSIONS

Flooding as natural disasters, which occurrence has been rapidly increasing, has great impact on structure of the cities and on the city networks. Thus, study the impact of such disasters, conducting vulnerability assessment and determining sensitive and high- risk areas of the city are essential in order to manage and reduce the risk of dealing with such disasters. In this paper the resilience of the city of Gothenburg against river-flooding is investigated. The methods applied in this research are comparing syntactic properties of the street networks and accessibility measurement. Analysis of the syntactic properties (NACH and NAIN) shows that the city configuration is influences by flooding and the degree of such influence is bigger at global scale rather than at local scale and stronger for NAIN values rather than for NACH values.

In the accessibility analysis, two parameters are measured; accessibility to different amenities in the city within 3 kilometres, and the minimum metric distance to amenities. The result of accessibility analyses shows that the city after flood L is more accessible than after flood H which is expected since the number of amenities and segments indirectly affected by flood H is higher than flood L. Furthermore, the influence of the accessibility is asymmetrically distributed in the city as the southern part of the city is more influenced after flooding compared to the northern part.

For the minimum distance, the numbers of indirectly affected segments, and the difference in the total length of their shortest distance to amenities, were examined. The result shows that although the impact of flooding on the minimum distance is relatively low, the healthcare centres show the maximum influence and the commercials show the minimum distance. It is also discussed that the reasons for such influence might be considered in the asymmetrical distribution of amenities, density of street network, topography of the city and existence of the sub-streams.

However the result shows that flooding (especially low-intensity flood) does not have a big effect on the minimum distance to amenities and from this perspective the city is highly resilient against the flood events. What should be noticed; however, is that the current results obtained from the analyses focused to measure the indirect impact of the flood events on the structure of the city. Therefore, the resilience of the city is examined only on the remaining part of the city and it does not consider directly inundated areas (Buildings and plots). In this view, more analyses of the street networks including the investigation of changes in the size of foreground networks, changes in accessibility of residential locations (address points) and examination of the other types of amenities are suggested in order to have a better understanding of impacts of such disturbances in the structure of the city, emphasizing that the resilience of a city depends on a set of many different parameters and cannot be confined to one or two parameters.
REFERENCES


ABSTRACT

This paper explores the use of weighted space syntax models to contribute to the process of integrated urban planning for Jeddah as part of a major planning project in the Saudi Arabia. The Municipality of Jeddah commissioned the production of an integrated suite of planning documents. These plans coordinate Strategic, Sub-Regional, Structural and Local plans across a citywide region and aim to provide a framework for sustainable urban growth and development over the next 20 years. This paper focuses on the space syntax methodologies used to aid urban planners to develop the Structure Plan and builds on the research used to develop the Sub-Regional Plan (Karimi et al, 2015). The Structure Plan studied how the urban structure of the city could accommodate the growth of population by about three million over the next 20 years. This included developing and testing a centres strategy to distribute population, employment and supporting facilities along with a public transport strategy for the city. For analysing the potential and requirements of the city, an Integrated Urban Model (IUM) was constructed to combine the spatial network with land use, population, employment and public transport. The aim of this model was to test the impact of changes in the distribution of population and employment. It also allowed the assessment of public transport alignments. The IUM is a key design tool for planning and optimising the relationships between population, employment and public transport. It was also used to provide a benchmarking methodology to compare options. Because the model links people to employment using the spatial network and public transport, the performance of options can be expressed in terms of benefits to the city’s population.
KEYWORDS
Integrated urban model, Design option testing, Centre hierarchies, Public transport strategy

1. INTRODUCTION
This paper aims to establish the capability of space syntax models to inform the planning process at a metropolitan scale. The paper investigates the applicability of an Integrated Urban Model (IUM) in the planning process for large cities rather than finding correlations between the spatial network measures and socio-economic phenomena. The study described in this paper is part of planning projects undertaken over the past three years to produce a growth strategy for Jeddah, Saudi Arabia (AECOM, 2014).

The project aimed to develop the Structure plan for Jeddah working with AECOM, an international multi-disciplinary planning consultancy. The Structure plan was based on outcomes established in the Strategic and Sub-regional plans which were developed prior to this project. Space Syntax Limited have already contributed to the development of the previous stages focussing on regional growth strategy, through advanced space syntax models and analysis (Karimi, Parham, Fridrisch, & Ferguson, 2013; Karimi & Parham, 2012, Karimi et al, 2015). The Structure Plan aimed to define distributions of population and employment at a fine scale (groupings of circa 60,000 residents), propose locations for centres (using the hierarchies defined in the Strategic Plan), develop the supporting urban systems and a public transport strategy (Karimi et al, 2015, AECOM, 2015).

Previously, large-scale space syntax models have been used to identify the key spatial characteristics of cities (Hillier & Penn, 1996; Hillier, 1996, 2001; Penn, Hillier, Banister, & Xu, 1998). These studies recognised a strong relationship between vehicular movement, distribution of land use, centre hierarchies with space syntax measures, such as 'Choice' (betweenness) and 'Integration' (closeness). These strong relationships have suggested that space syntax analysis could be used as an explorative model to understand large spatial systems better and also inform the processes of urban planning and design (Hillier & Stonor, 2010; Karimi, 2012; Penn, 2008).

However, a standard space syntax model, which only analyses the spatial system based on its geometric configuration lacks the ability to highlight the nuances of a rapidly developing city like Jeddah. The existing measures also lack the ability to test the impact of proposed changes which do not involve the change of the spatial network like a change in the distribution of densities and jobs. The model also struggles to test the impact of proposed developments where data regarding the proposed spatial structure is not available.

The Integrated Urban Model (IUM) was developed to respond to these issues. The IUM is a weighted spaces syntax model which combines the spatial model of the city with other data sets like land use and public transport systems. The IUM can assess the combined impact of proposals, and inform the development of individual urban components or systems.

This paper investigates how space syntax models can be enhanced by combining the spatial model with various other datasets to create an IUM; and secondly, explores how an IUM can help planning processes like the distributing density at a fine scale, designing a hierarchy of centres and developing supporting urban systems like public transport.

The questions this paper will explore are -

• How can urban datasets (population, employment and public transport) be combined with space syntax spatial models to create an IUM?
• How can an IUM test the impact of changes to land use on activity and movement patterns of Jeddah?
• How can an IUM communicate results in a form easily understood by architects, planners and clients?
• How can an IUM assess the impact of different urban elements simultaneously rather than in silos?
1.1 CONTEXT

The study is based in Jeddah, Saudi Arabia. Jeddah is a major port located on the eastern coast of the Red Sea and is fast becoming a regional economic centre. It remained a traditional Arabian city till 1950 with a population of around 35,000, living within the walled city (Daghistani, 1993). Since then the city has grown massively and the region now has a population about 3.6 million and is predicted to reach an estimated population of 6 million in 2033 (Daghistani, 1993, AECOM, 2013, 2014, 2015). The uncontrolled growth post-1950 has left the city with an extensive, poorly focused structure. This urban condition has resulted in dependence on car travel, overcrowded roads; and service infrastructure, which does not reach all citizens (El-Shafie, 2010). The overarching aim of the Structure Plan was to address the existing urban condition and ensure that urban growth can be effectively managed over time in a sustainable way.

Hillier (2009) defines ‘spatial sustainability’, through the geometry and configurational ordering of spaces in a city. The generic form of a city is defined as a foreground network of streets, centres and sub centres across scales set in a mainly residential background network. This arrangement is a by-product of the micro socio-economic forces acting on the city. This combined with the process of minimising travel time by increasing accessibility between different spaces in a city results in a self-organised sustainable spatial system (Hillier, 2009). The foreground network is shaped by microeconomic forces representing the invariable patterns found in all cities, while the background network, defined by the socio-cultural forces varies depending on the cultural and social practices prevalent in the city. The balance between the microeconomic and socio-cultural forces define the spatial growth of a city (Hillier, 2002). The spatial configuration of the street network generates movement and results in some streets being preferred as routes and destinations in the city (Hillier, Penn, Hanson, Grajewski & Xu, 1993). Hillier et al (1993) argue that high footfall-dependent functions, such as retail, locate themselves on streets with a high potential for natural movement, while streets with a lower movement attract land uses like residential, which seek low movement. In addition, functions like retail and commerce attract even more movement, contributing to the inherent high movement potential of the street. This cyclic process results in such streets or centres acting both as routes and destinations (Griffiths, Vaughan, Haklay & Jones, 2008). These patterns are found universally in most cities (Hillier, 2002).

However, these patterns are not observed in Jeddah. The growth pattern of Jeddah and other cities in the developing world have shown similar trends to the New Towns in the UK, with mono-functional land use zones, inward facing urban blocks and a motorway dominated movement network (Karimi, 2009). These trends coupled with a disregard for the existing organic spatial structure while planning has caused deterioration of parts of Jeddah and led to unorganised urban growth (Bahaydar, 2013).

Jeddah has no consistent centres hierarchy across the city, with the spatial hierarchy, activity centres fragmented across the urban area. This is compounded by the sporadic nature of planned development with major projects often permitted in isolated locations. The city structure is characterised by linear form, resultant of a dominant foreground structure as the road structure was designed to enhance vehicular travel. People have to travel significant distances to access their daily needs and employment destinations. The city’s growth is the major contributor to this condition. Small scale, high density, a walkable urban form developed organically until the 1970s was replaced by low-density, vehicle-scale, sub-divisions and unintelligible street networks. Local scale commercial centres are found in the older, denser areas (unplanned settlements). The planned parts of the city contain almost no local Centres. Larger commercial centres are formed by long, linear strip development alongside highways infrastructure. With commercial uses spread along road frontages, activity is spread out and diluted, resulting in very few nodes of commercial activity. This urban development pattern coupled with the hot and humid climatic conditions is not conducive to walking given the length of these commercial centres. (Karimi, Parham, Fridrisch, & Ferguson, 2013; Karimi & Parham, 2012, Karimi et al, 2015, AECOM, 2014).
2. DATASETS AND METHODS

2.1. INTEGRATED URBAN MODEL

Cities are complicated combinations of physical form, infrastructure systems, human networks and economic activities that create complex systems. Physical changes to the city may have unexpected impacts on these systems, and on the day-to-day functioning of the city. The IUM was developed to combine these different layers or urban data to spatially analyse the city to understand the city-wide impact of design, relationships between key parts of the city or the specific relationships within layers of the model. The IUM is a GIS-based model that uses a representation of the spatial network to link multiple layers of data. It aims to provide a quantitative spatial model to assess how successfully proposals would deliver the objectives of the Structure Plan. The model provides a robust analysis considering the impact of various urban elements, rather than treating each component as a silo. The spatial network includes vehicular networks, pedestrian spaces and the public transport network (each of which can be turned on or off depending on the mode of transport), while additional layers include land use, population and employment (Figure 1). The model is processed in Depthmap to generate the space syntax measure of weighted choice.

Figure 1 - Components and outputs of the Integrated Urban Model
2.1.1 SPATIAL NETWORK
The spatial network uses a space syntax model of the city as a base. These models have been created for the existing city and multiple proposal options. The motorway interchanges and multi-lane highways were consistently simplified to the fewest possible lines. Spaces have been categorised according to those which are accessible only to vehicles, those which are accessible to vehicles and pedestrians and those which are accessible only to pedestrians. This allows analysis to be carried out using any combination of these networks. To carry out catchment analysis and characterise the public realm, the vehicular network has had peak-time average speeds assigned in relation to their allocated hierarchy. Peak traffic speeds have been estimated using survey data on existing average journey speeds. The following speeds are the result of this process:
- Metro 90 km/h
- Highways 50 km/h
- Strategic/Arterial Routes 50 km/h
- Collector/Distributors 45 km/h
- Local Roads 35 km/h
- Pedestrian Only Routes 5 km/h

2.1.2 PUBLIC TRANSPORT
The public transport network represented in a different way to the spatial network. When moving across a city, the use of public transport is based on a different type of way-finding decision to moving on foot or by car. The direct connection between stations is more important than identifying the easiest route through the street network. As a result, public transport is represented as a topological set of links that may not follow the street network but which link proposed station locations. As with the spatial network, typical speeds have been assigned to the public transport network which enables it to be included in any catchment or coverage analysis. The average speeds associated with each mode of public transport are:
- High-Speed Rail 50 km/h
- Commuter Rail 40 km/h
- Mass Rail Transit 30 km/h
- Light Rail Transit 15 km/h

2.1.3 LAND USE
Land use data was provided in GIS format. Data was combined from several surveys at the plot level:
- Qattan survey (2007)

Data from each survey required work to become consistent with a set of overall and detailed uses. The GIS tables had varying data structures, land use distribution and overlapping data which was merged into one combined dataset. Where survey data was contradictory or unavailable but development could be seen in aerial satellite photography, missing plots were added to the GIS dataset. Land use was allocated to these blocks either based on correspondence with colleagues in Jeddah or information available online. Preliminary checks on the accuracy of land use data were made through the processes of distributing population and employment and the inaccuracies were corrected where necessary.
The plots were divided under the following land uses:

1. Low-Density Residential - Villas
2. High-Density Residential - Apartments
3. Unplanned Housing
4. Offices
5. Retail
6. Shopping Malls
7. Hotels
8. Light Industry
9. Heavy Industry
10. PowerStation/Refinery
11. Port
12. Warehouses
13. Educational services
14. Health Services
15. Religious services
16. Government

2.2 SPATIALISING DATA

Each data set combined in the model had a different origin format: the spatial model focused on street segments between junctions, land use data was available at the plot level across most of the city, while non-spatial demographic and economic data was available at the level of the city and the employment sector.

One of the key roles of the IUM is to spatialise data sets from different sources and combine them. To do this requires a consistently defined spatial element. A series of regions called “superblocks” were defined within the city and used to distribute non-spatial data, and to aggregate plot level and street segment data (Figure 2). The following urban elements were used to define superblocks:

1. Major routes or the foreground network defined by Global Normalised Choice value above 1.3 (Karimi et al, 2015).
2. Significant changes to morphology occur like the unplanned settlements or large single use plots (Figure 2).
3. Existing municipal district boundaries.
4. Mega projects being built or to be built by 2033.

The motorways and highways, which are the longest street segments, were not included within the superblocks boundaries and no weightings were applied to them. This was due to the fact that it would not be possible to access any land use from the motorways and thus they would not generate or attract any movement by themselves and only act as routes (Karimi et al, 2015).
2.2.1 POPULATION AND EMPLOYMENT

The population was distributed across the city based on the type and amount of residential land use (Figure 3) (Karimi et al, 2015). The number achieved was not meant to be a precise amount of people living in those plots, but an indicator of residential densities distribution across the city. Once finalised, populations per district were checked against the overall census figure of 2010 and found to be within 5%.

For employment, the total workforce from the 2013 census data was divided into various sectors based on assumptions developed by the planners through their experience. Like the population, the number of jobs was only an indicator of a proportional distribution of employment density. Employment was distributed to the plots based on their Gross floor area (Karimi et al, 2015). Along with the population and employment numbers, the centre of large employment and movement generators like the airport and port were included in the model (Karimi et al, 2015).
2.3 PROCESSING THE WEIGHTED MODEL

The distributed population and employment numbers were used as origin and destinations in a weighted space syntax model. Each street segment was weighted by the number of trips it generated as an origin or destination within the city. The system of weighting was based on the potential of each land use to generate movement. This potential is expressed in the form of the number of people living (origin) or working (destination) in the urban plot. In this approach, the impact of land use is transformed to a currency of movement, or ‘urban activity’, in a spatial network model.

After the weightings are applied to the street segments, the model is processed in Depthmap using OD weighted angular segment analysis (Karimi et al., 2015). In an un-weighted segment angular analysis, the Choice value of a segment is calculated based on the angular change during a trip from origin to destination and the final Choice value is the summation of all the trips that pass through the street segment (Hillier & Iida, 2005). However, in a weighted segment angular analysis the Choice value gets multiplied by the product of the origin weighting of the street segment the trip started at and the destination weighting of the segment where the trip ends (Karimi et al., 2013, Karimi et al, 2015). The public transport network functions only as a set of links between parts of the city and has no origin or destination weightings. The principles of weighing space syntax measures have been explained in detail in another publication (Karimi et al., 2013, Karimi et al, 2015).

3. MEASURES

3.1 URBAN ACTIVITY INDEX

Urban Activity Index describes the total potential level of activity taking place on a street (Figure 4). It was calculated by normalising weighted Choice values using Total Depth values.
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at the respective radii. The measure shows the number of times each space is used to link all other spaces taking population and employment into account. It combines the people passing through the street as part of a wider journey as well as people occupying the surrounding plots as their place of work or residence. It identifies the distribution of activity across the whole city with streets recording higher values tending to pick up more movement, retail uses, and pedestrian activity.

3.2 CENTRALITY INDEX

Centrality Index analyses the connections within the network to identify areas which are easier to get to from all other places (Figure 4). The measure was the combination of the log of weighted choice at a radius of 2, 5 and 10 km. These scales were used to represent the micro, meso and macro scales of centrality. Spaces which are easier to get to by vehicle, public transport and on foot, have been seen to correspond with the active functions of a city which are found in centres. Therefore, proposed town, multi-district and district centres should correspond with parts of the city that record higher Centrality Index values.

![Figure 4 - Urban Activity index (left) and Centrality index (right) measures](image)

4. APPLICATION

4.1 LOCATION PROFILING

The IUM was used to profile and compare multiple locations which have been identified for the same potential use (for example centre locations). Any combination of the attributes included in the layers of the spatial network, land use, population or employment can be used. For example, the location of a centre can be assessed to see whether it has a suitable level of accessibility, if it contains any of the functions a centre requires; or whether it contains enough vacant land to
accommodate new uses. Potential multi-district and district centre locations were assessed in terms of accessibility, whether they already have any of the facilities required for that category of the centre within 400m, and how much vacant land is within 400m.

4.1.1 IDENTIFYING SUITABLE CENTRE LOCATIONS

The existing structure of the city has no consistent centres hierarchy across the city with activity centres and land use fragmented across the urban area. Spatial analysis showed there are very few areas where different scales of spatial accessibility overlap which is common of successful city centres. The centre strategy proposed by the Structure Plan defined a hierarchy of centres that combined different levels of commercial use with community facilities and higher residential densities. The Structure Plan proposed locations for Town, Multi-District and District Centres. Weighted choice was used across scales to look at pedestrian scale movement for local centres, cyclist scale movement and district centres, vehicular scale movement and multi-district and town centres. Centrality was the key measure to identify centres. Some spaces are closer to all other spaces as they require fewer steps to cover the entire network. These spaces tend to be the areas of a city where facilities that more people need to access are located, and they correlate well with the city centre land uses. Centre types were addressed sequentially, starting at the Town Centres and working towards the District Centres as locations of higher order centres would have an impact on infrastructure, public transport and densities, which in turn would affect where the lower order centres are placed.

4.1.1.1 TOWN CENTRES

The proposed locations for town centres identified by AECOM were predominantly large vacant sites around the city that would be developed through detailed masterplans. The most useful comparative measure to assess Town Centre locations is city-wide scale Urban Activity Index as the location of these centres would have a high impact on the city through the implementation of the proposed masterplan and also shape the public transport system. The boundaries of these locations were defined and the IUM was used to compare them. The average global Urban Activity Index values of all streets within these boundaries were compared. These values were used to reflect how well connected each site is to the rest of the city. Since the comparison was of global values the lack of a finer grid on these sites was not a big setback. The locations with the highest average values would provide the best combination of accessibility to the local and wider city (Figure 5).
Figure 5 - Process of identifying and testing location of centres across hierarchies
4.1.1.2 MULTI-DISTRICT AND DISTRICT CENTRES

Once the Town Centre locations were identified, major public transport alignments were identified to best link them together. These alignments influenced the ultimate routes, interchanges and modes proposed in the accompanying transport plan and also had a subsequent influence on the location of both Multi-District and District centres.

The role of Multi-District Centres and District Centres was to serve multiple “superblocks”. Thus the potential locations that covered superblocks most efficiently were located at the intersection of ‘superblocks’. These intersections were represented as a series of points in the network.

Multi-District Centres should be located in the strongest location close to the intersections of public transport lines. They were identified by plotting proposed public transport alignments and identifying the intersections between superblocks that coincided with the intersections between public transport alignments. District Centres should be located in the strongest locations along public transport alignments and were identified by plotting the intersections of the superblocks with proposed public transport alignments. To provide alternative locations, potential sites were extended to include the points where immediately adjacent superblocks meet (Figure 6).

Multi-District Centres and District Centres need to be accessible to the wider city, but also to local pedestrian and cycle scale movement. As Multi-District Centres and District Centres are smaller and will make less change, more of the existing street network will be retained. Locating these Centres requires an understanding of the existing network. To understand how these scales of access work together at each point, Urban Activity Index values were combined to include pedestrian, cycle, city-wide scale (using the vehicular network).

To analyse which locations were strongest, a 400m catchment area was defined from all potential points using plot edges. The IUM was used to extract average Urban Activity Index values within this catchment area.

4.1.1.3 MULTI-DISTRICT AND DISTRICT CENTRES: DEVELOPABLE LAND ASSESSMENT

While some Centres would develop organically due to the increases in land value from the introduction of public transport infrastructure, the availability of vacant land would also contribute to their development potential as it would attract private sector commercial development, higher density residential development and to provide community facilities.

Once potential locations were compared using the Urban Activity Index, a second comparison was carried out by looking at developable land around that location. Using the 400m catchment area from potential centre locations, all currently vacant plots were identified and the total area was calculated. The immediate priority of vacant land in Multi-District Centres and District Centres was to provide community facilities, as commercial and higher density residential development can occur over time.

Based on proposed populations, the required community facilities based on municipality standards were identified and the accompanying plot area was calculated. The total plot area needed for these facilities was subtracted from the existing vacant land to define the developable area. Each potential centre location was then plotted on a drawing showing how well connected it is locally and globally with how much developable land is present. The best locations for centres had higher Urban Activity Index values and more vacant land.

4.2 CATCHMENT ANALYSIS

Analysis of the relationships between specific land uses was carried out using a different methodology. Individual plots (containing land use, population and employment data) were linked to the nearest adjacent street segment. This allowed routes to be traced from any plot through the street or public transport network until they reached a defined destination, covered a certain distance or travelled for a set time. This analysis allowed specific land uses to be tested in terms of the number of residents they served.
4.2.1 IDENTIFYING EXISTING LOCAL CENTRES

Land uses across Jeddah were analysed to determine to what extent centres exist or partially exist within the city. Determining the extent to which centres exist was based on looking at the relative location and clustering of commercial, higher residential density and community facility uses; and how accessible these locations are within the city using catchment analysis. The location of the facilities was identified using the GIS land use database. Metric catchments of different sizes specified distances (relating to the level of centre) were then generated through the spatial network. Overlaps between the metric catchments from the required facilities were analysed to identify clusters of existing facilities which met the requirements of the municipality standards.
4.2.2 COMMUNITY FACILITIES

To test community facilities standards required linking every residential plot to each type of facility. Traditionally when this has been done using “as the crow flies” radii, it is very difficult to ensure that where school catchments overlap each residential plot is only linked to a single facility. The impact is that some schools could appear to be over capacity as one residential plot could be linked to two schools. This problem has been avoided in the IUM because each residential plot is linked once to the closest facility following the most accessible, fastest route.

Analysis of catchment populations was then run by using the facility as an origin, moving through the street network until the defined distance has been covered, and calculating how many residential plots are linked to that facility. With the plots accessing each facility identified, the total population within this catchment was calculated and compared to standards to identify whether it is over or under capacity (Figure 7). This was used to identify the impact on vacant land available for development, once the required number of community facilities have been implemented for proposed populations.

Figure 7 - Linking plots through the spatial network allowing relationships between specific plots and land uses to be calculated
4.2.3 ACCESS TO PUBLIC TRANSPORT
Analysis of the coverage of public transport options was carried out using catchment analysis. 15-minute catchments (by any mode of transport) were defined from proposed public transport stations and interchanges. The plots falling within these catchments were identified and translated into a proportion of residents within a 15-minute journey of public transport.

4.2.4 ACCESS TO PROPOSED TOWN, MULTI-DISTRICT AND DISTRICT CENTRES
Catchment populations were calculated from proposed centres that provide employment (town and multi-district centres). 30 and 15-minute travel times (using any mode) were used to define these catchments. Residential plots falling within these catchments were analysed to measure how many centres, and therefore opportunities for employment each plot has access to and what proportion of the population this equates to.

5. DISCUSSION
5.1 NEED FOR A WEIGHTED SPATIAL MODEL
Jeddah offered some unique spatial challenges for space syntax analysis to address. Many parts of the city had been subdivided by a street grid but were uninhabited. Unweighted space syntax models can be used to analyse the structure of the city based on its spatial configuration. This process overestimates the movement potential of the uninhabited grids. In reality, these grids would not generate any movement. The unweighted model would struggle to highlight these nuances of the existing cities structure.

The project required Space Syntax Limited to test the impact of changes to population and employment densities, proposed developments which lack spatial data. Since the unweighted model struggles to test the impact of proposed changes which do not change the street structure, the weighted space syntax model was developed. The effect of weighting in the context of the existing city was that street segments in an uninhabited sub-division (of which there are many) would not generate or receive any trips, however, they still allow movement through them if they form part of a wider journey. The weighted model also helped test the impact of different distributions of densities and developments by weighting the respective segments with origins and destinations.

While calculating the weightings, no specific time scenario (morning or evening) was modelled. The aim was to understand the potential urban activity caused by the spatial changes rather than the amount of movement generated at specific time periods. Hence the model was weighted as if all the population and jobs were impacting the model at the same time.

5.2 HOW IUM HELPED IN THE PLANNING PROCESS?
5.2.1 IDENTIFYING THE OPPORTUNITIES AND CONSTRAINTS OF THE EXISTING CITY
The analysis of existing centres and community facilities determined that it would be very difficult to deliver the current municipality guidelines for community facility standards in the existing urban context. This was due to the large number and size of facilities required, limited amount of suitable vacant land parcels in required proximity, and the existing street network and block structure that was not conducive to developing centres. The number and various types of facilities required may also be unsuitable for some parts of the city. Accordingly, it was necessary to revise the community facility standards to the context of the city.

The catchment analysis helped identify gaps in the existing distribution of social infrastructure. By connecting schools, hospitals etc. to their respective residential catchments, parts of the city with no coverage were identified. This helped locate the parts of the city which required immediate focus and helped develop a phasing strategy.
The catchment analysis also helped develop a phasing strategy for the development of the public transport system. The results of the analysis of mapping the existing and proposed population and employment catchments from the proposed public transport lines, allowed the planners convince the client to choose the line which would benefit parts of the existing city the most, rather than the line which was going to connect the proposed mega projects.

5.2.2 ITERATIVE DESIGN PROCESS

The IUM provided the tools to test whether design options achieved the aims set out in the Structure Plan. The impact of spatial changes, land use distributions, public transport options were tested simultaneously. In an iterative design process, options for population and employment distribution, the location of centres, and public transport lines and station locations were developed, tested and refined to be in line with the desired sustainable growth principles (Figure 8).
5.2.3 COMMUNICATING RESULTS IN TERMS OF BENEFITS TO THE CITY

The aim of the IUM was to present the outcomes in clear and precise terms which could be easily understood by the planners and the clients in terms of benefits to the city’s population. It was integral so that the iterative design process worked efficiently to develop the best options.

‘Difference Maps’ were used to translate the results of the spatial analysis into a map which showed the impact of the design options on different parts of the city (Figure 9). Difference Maps do not show the emergent hierarchy of the city but identify the areas where the biggest (positive and negative) changes occur. This helped identify the area’s most likely to attract development and areas which needed more attention to ensure they developed into successfully.

Figure 9 - Difference Map - Spatial network coloured according to change in Urban Activity Index. Red segments show an increase on existing levels of activity, blue segments show a decrease, while grey segments are spaces which did not undergo any significant change.
The results of all catchment analysis were visualised as thematic maps to show variations in coverage, and as graphs that allow a comparison of residents’ access to centres across options. The outputs were in percentages of people served or a number of centres or stations which helped communicate the impact of design options with clarity with the planners and the clients. The preferred option was selected as it created the following benefits:

- Around 5m people (80%) would be within a 15-minute journey (on foot, by Car, or by Metro) of a centre, and the employment, education and health facilities they provide (Figure 9).
- Around 2.5m people (40%) would be within a ten-minute walk of a Public Transport station (Figure 10).

Figure 10 - Centres within 30 minutes.

How many proposed centres are within a 15 minute trip of all residential segments using an means of transport?

Figure 11 - A thematic map and Graph helping communicate the results of speed based catchment analysis showing how many proposed centres can be accessed within 15 minutes of all residences using any means of transport.
How many people can access a station within a 15 minutes using any means of transport?

Figure 12 - Time to public transport

Figure 13 - A thematic map and graph helping communicate the results of speed-based catchment analysis showing how many people can access a station within a 15 minutes using any means of transport.
6. ACADEMIC CONTEXT VERSUS PRACTICE / PROJECT DECISIONS

The methodologies and measures developed to test the growth scenarios were designed to aid the planners to make the best decisions to achieve the aims of the Structure plan. The methodologies may not be academically robust but tried to provide the most accurate results in light of the data available. For example, while distributing weightings to segments the data was aggregated up to the superblock level from the plots and then distribute to the segments as a proportion of their segment length. This was done as the superblocks were a useful output area for the planners to work with as they responded not only to the spatial conditions of the city but also administrative boundaries and proposed projects. This helped the planners make decisions which would be in line with the city’s municipal structure and not drastically against the proposed developments which were already approved for development. Aggregating the land use data to superblocks was also an effective way to distribute population and jobs as there was no data available regarding the entrances of the buildings.

Another example was identifying potential locations for Town, Multi-District and District centres. The hierarchy of centres and their initial locations were developed to try and respond the existing issues of the cities and the framework developed by AECOM in the Strategic, Sub-regional and Structure plans for the city. The measure and scales used were also selected to best answer the questions posed by the planners. Since there was no actual movement data available it was not possible to compare the measures with actual movement to see if they had a statistically relevant correlation.

7. CONCLUSIONS

The IUM was a key design tool in refining the plan and optimising the relationships between population, employment and public transport. Linking the spatial model to land use and public transport allowed queries of multiple conditions to be carried out simultaneously – e.g. where in the city is a potential centre location which is accessible both globally and locally has vacant land and has a specific existing population density. The IUM thus allows planners to work across departmental silos and test the impact of different urban components simultaneously.

The IUM was used to provide a benchmarking methodology to compare options in terms that a non-expert could easily interpret. For example, what is the number of jobs within 30 minutes of all residential land uses rather than accessibility values of segments. This allows the planners quickly assess the options in regards to the aims of the plan and also help communicate with clarity with the clients with clarity why an option was chosen.

Subsequently, the IUM was also used for the Jeddah Metro project where Space Syntax Limited worked with an internationally renowned architectural firm to profile the metro routes, categorise stations, and test station locations etc. Since the proposed plan for the Metro system was based on the Structure Plan the IUM helped link the outputs of the Structure plan and the detailed design of the Metro system to ensure a sustainable design of the public transport system.
REFERENCES


A STUDY OF THE MORPHOLOGICAL EVOLUTION OF THE URBAN CORES OF BAGHDAD IN THE 19TH AND 20TH CENTURY

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ABSTRACT
The urban development processes of Baghdad witnessed important phases of modernization, as evident in its evolving urban grids. By the early period of the 19th century, an organic grid of its main historic core emerged with a grid system applied by the colonial power to control and guide the urban growth along the course of the River Tigris. In the late of 1950s, the first rectilinear grid street patterns were adopted to manage the new expansion along the northwest-southeast axis, and suburbs were introduced characterizing faster growth at urban edges. Throughout this modern evolution, many planning practices were applied that pushed urban growth in all directions, ultimately forming a much bigger city around the historic urban core of Baghdad. In the 2000s, the size of the metropolitan city has become huge with various patterns of urban grids, producing a high sense of spatial complexity.

The main purpose of this paper is to study the syntactic properties of the spatial urban cores of Baghdad in the 19th and 20th century by using space syntax techniques and measures. The paper analysed six historical phases of the city - 1900s, 1920s, 1940s, 1960s, 1980s, and 2000s - showing significant changes in the urban grid. Two key measures, integration and choice, of space syntax were adopted to identify the syntactic typologies of urban cores. Major distinguishing patterns, which generally tend to interact with growth trends of the built environment, for each phase were identified.

Findings show that there have been significant changes in the typologies and locations of syntactic urban cores from one historic phase to another of the city. Some of the identified patterns undermined the common notion of the inevitable correlation between commercial activities and integration cores, and appeared more interactive with planning practices influencing the density and direction of urban growth. Future research study should include the evolution of the morphology of the city since its inception in the 7th century CE; and should apply the same approach on a limited scale to other urban units, such as districts and neighbourhoods.

KEYWORDS
Space syntax, syntactic properties, urban cores, modernization, Baghdad

1. BACKGROUND
Despite a commonly accepted understanding of the complexity of cities, many Middle Eastern cities appear to be more complex than other cities due to the path of emergence and growth peculiar to these cities. Like many other organic cities, they developed in response to topography, climate, and societal needs (Elsheshtawy 2004, Hakim 2013). The organic patterns
of these cities were often characterized by narrow zigzag roads and cul-de-sacs, compact urban clusters, low-rise buildings, small urban blocks, and a mixture of land uses. They lack the basic properties of modern urban planning, such as repetition, symmetry, rhythm, and alignment (Alobaydi and Rashid 2015, Hakim 2007).

After hundreds of years of organic development, the infrastructures of these Middle Eastern cities were reformed using modern planning practices, carried out by the European colonial powers in the early 19th century (Al-Ashab 1974). These modern practices included, but were not limited to, the use of an orthogonal layout, highway systems, superblocks, and zoning aimed to control and manage the physical, social, and economic resources of these cities. For example, several master plans based on the modern planning principles were prepared for the development of the City of Baghdad. The most important ones were applied between the 1900s and the mid-1960s restructuring the city form of Baghdad (Elshehawy 2004, Pieri 2008). As a result, a combination of organic and grid patterns had developed throughout the British Mandate and Iraq Monarchy. However, with the emerging interest in the legitimacy of the National Republican Rule of Iraq during the late periods of 1950s, the patterns were modified and infused with rigid rectilinear forms, as the automobile became a primary mode of transportation. The rectilinear forms extended over a vast area beyond the old historic core of the city. By the 1980s, main boulevards and highway systems have isolated the organic historic nuclei, including Old Baghdad, al-Kadhimiya, and al-Adhamiyah, from the whole network system of the city. The rapid growth of the city helped decrease the urban density of the historic core by increasing it at the urban edges. Now, in the 2000s, the size of the metropolitan city has become huge, and it contains various patterns of urban grids creating a high sense of spatial complexity (Alobaydi and Rashid 2015). For an illustration of the important planning features of Baghdad in the 2000s see (Figure 1).

Past research evaluating the development of syntactic urban cores in the Middle East region has been limited at the scale of historic nuclei. A review of the existing literature found many studies that cover many issues such as socio-economic influences, landmark spatialization, movement

Figure 1 - The map shows the main planning features and historical morphological phases of Baghdad
densities, and modern planning implications (Asami et al. 2003, Griffiths 2009, Griffiths et al. 2010, Karimi 2012, Rashid and Alobaydi 2015, Rashid and Bindajam 2015). However, they do not sufficiently illustrate the morphological variations of the syntactic urban cores of a typical Middle Eastern city. So far, studies involving syntactic measures, such as integration and choice, show that the prevalent structural properties of urban cores formed during historical phases of modernization often cluster beside and around socio-commercial activities of Baghdad (Alobaydi and Rashid 2015). During the last two phases, however, these cores might have interacted more with modern planning practices to manage the density, pattern, and direction of the growth of this city. Therefore, the purpose of this study was to explore the effects of modern planning practices on the evolving urban core of Baghdad. More specifically, it would like to explore, how were the syntactic urban cores changed from one phase to another due to modern planning practices, and how can these changes be described and classified?

2. METHODOLOGY
For its purpose, the study uses space syntax approach, which was founded by Hillier and his colleagues (Hiller 1984, 2007). Two common measures of space syntax, integration and choice, were chosen here to analyse, identify and describe the development of urban cores in several historical phases of Baghdad. For each phase, the study consists of three main parts: first, it describes the spatial framework of the city based on land use distribution; then, it identifies the integration and choice cores found in these phases; and, finally, it visually correlates the identified patterns of syntactic urban cores to land use activities and/or different planning practices. Therefore, the space syntax approach is discussed in detail in the next section.

2.1. SPACE SYNTAX APPROACH
Space syntax is a set of theories, techniques, and measures for studying the syntactic properties of the configurations of streets structures and open spaces. One of the most important techniques of space syntax is the axial map, which has been applied to study spatial layouts at different scales, ranging from a single building to an entire city. Another more recent space syntax technique is the segment map, which is formed by breaking down each axial line at the intersections with other lines. Using the techniques and measures of the axial and segment map analysis, many researchers have demonstrated how the accessibility and connectivity of spaces can be used to explain observable social phenomena including socio-economic patterns, movement density, and land use distributions (Griffiths 2009, Hanson 1989, Hillier 2005, Hillier 2007, Hillier et al. 1987, Peponis et al. 1989, Rashid and Alobaydi 2015, Rashid and Shateh 2012, Rashid and Bindajam 2015).

As noted above, this study used the integration and choice measures of space syntax, which are described below.

- **Integration measure**

  One of the most common measures of space syntax is the integration, which indicates how accessible/connected a line is in relation to all the other lines in the map. Therefore, high integration values indicate lines that have better connections while low values refer to lines that have fewer connections with the other lines. The integrated values are represented graphically on the map using a scale of colours that range from red referring to highly integrated streets, to blue referring to the segregated streets.

  Integration values can be computed at different radii. For example, the integration value at radius-3 of a line uses only those lines that are three steps away for the given line; the integration value at radius-5 uses only those lines that are five steps away for the given line; the integration value at radius-7 uses only those lines that are seven steps away for the given line; and so on. The integration value at radius-n of a line considers the n-steps needed to cover all the lines in the whole system (Hillier 2005, 2007). Therefore, the integration value computed at a lower radius describes a more local syntactic property than that computed at a higher radius. Note, however, that the most local of any syntactic property of a line is its...
connectivity value, which is the number of lines directly connected to the line.

Integration Core: It is often defined by the most integrated 10% of all the streets in a network of streets. The segregation core, in contrast, refers to the least integrated 10% of all the streets in a network of streets, and is often located in and around less accessible places (Hillier et al. 1987).

Choice measure

The other key measure of space syntax utilized in this study is choice. Unlike integration, choice gives the degree to which a line lies on the simplest paths from one line to another line in the network. The choice value of a given axial line is determined by dividing the number of shortest paths between any two lines in the axial map containing the given line by all the shortest paths between any two lines in the map (Turner 2007).

In simple terms, integration measures how easy it is to go from one line to all the other lines of a network, thus indicating the potential of a line for to-movement. In contrast, choice measures indicate how likely it is for a line to be chosen on the potential paths from one line to another in a network and thereby indicating its potential for through-movement (Hillier 2005). Clearly, what is implied here is that users want to maximize their accessibility to all physical spaces by to-movements and to minimize efforts by through-movements from one space to other spaces.

Choice Core: It is often defined by the 10% of all the streets in a network of streets with choice values higher than the rest. The core with least choice, in contrast, is defined by the 10% of all the streets in a network of streets with choice values lower than the rest (Hillier et al. 1987).

2.2. DATA COLLECTION AND METHODS

The data included the maps of Baghdad representing the early period of the last century up to the present stage of the city. The majority of the old maps were drawn by Western geographers and explorers who visited Baghdad before and after WWI (Al-Ashab 1974). For this paper, the six historic maps representing the 1900s, 1920s, 1940s, 1960s, 1980s, and the 2000s were collected and integrated to identify the most important phases of modernization of the city.

The sources for the used maps included Al-Ashab (1974), Municipality of Baghdad, the Centre of Urban and Regional Planning at the University of Baghdad (CURP-BU), the Central Library at BU, the Ministry of Planning in Iraq, the Watson Library at the University of Kansas (KU), and the Libraries of the University of Texas (UT) at Austin. Between the 1970s and the 2000s, information pertaining to the urban forms of Baghdad was rare because of the security restrictions imposed by the al-Ba’ath government. Therefore, a recent satellite image (2008) provided by CURP-BU was integrated and used to study the current phase of Baghdad.

While Baghdad in the 1900s experienced organic developments in and around the historic urban core, the next two phases in the 1920s and 1940s reflect planning practices that were used by the colonial government in power and the Iraqi Kingdom through the Iraqi Development Board (IDB), or Majlis al-A’mar (Pieri 2008). Different sets of modern planning practices and norms were applied to manage city development and extension during the 1960s and 1980s. Rapid urban development from the al-Ba’ath regime (1968-2003) up to the present also used many modern planning models that accelerated the expansion of grid patterns, particularly in suburbs and urban edges. Urban explosion is the best term to describe the current phase of Baghdad (after 2003) because of unprecedented urban sprawl (Alobaydi and Rashid 2015).

2.3. PREPARING AND DIGITIZING DATA

Due to the cartographic differences between the satellite image and the scanned old maps, first georeferencing, which is the process of assigning spatial coordinates to the used maps, was applied. In the georeferencing operation, important landmarks and streets that have not changed from one phase to another were used. It should be noted that some parts of these
scanned maps, particularly in the urban edges, did not entirely match each other due to the inherent differences in the map-making methods used, which became a limitation for this study. For each map representing a historical phase, the axial and segment maps were created using space syntax techniques to represent the spatial configurations of urban cores.

2.4. STUDIED SCALES

Because the city form has changed significantly over time, the size of the examined areas also increased from one phase to the next. The first historical phase (1900s) was located inside the limits of Old Baghdad (al-Rusafa and al-Karkh) (Figure 1), and had a measured area of 6.5 sq. kilometres (2.5 sq. miles). The second historical phase had a measured area of 34.7 sq. kilometres (13.4 sq. miles). The third development phase (1940s) had an area of 47 sq. kilometres (18.2 sq. miles). The fourth development phase (1960s) had an area of 65.7 sq. kilometres (25.4 sq. miles). The fifth development phase (1980s) had an area of 314.2 sq. kilometres (121.3 sq. miles). For the last phase, the metropolitan city of Baghdad measured 379 sq. kilometres (146.3 sq. miles).

3. RESULTS AND DISCUSSION

Results and discussions for each identified pattern focus on linking the syntactic urban cores defined using the integration and choice values with land use patterns and planning practices to identify the urban density and growth trends in Baghdad. The identified patterns found in the historical phases of modernization in the city since the early 20th century can be described as follows:

3.1. TREE AND LINEAR PATTERNS

The tree patterns of integration and choice cores are found in the axial and segment maps of the first phase of Baghdad's map. These cores were formed on the al-Rusafa side where the building density had increased significantly during this phase. In 1900s, Baghdad was generally held to be the archetypical organic city in the Arab-Islamic environment. Built by the influences of socio-cultural traditions and economic processes without the preplanned design, the city contained dense and overcrowded clusters, short irregular blocks, zigzag network-roads, cul-de-sacs within huge boundary walls and gates (Al-Ashab 1974, Elsheshtawy 2004). Unlike institutional and commercial areas, residential clusters were overcrowded with a full coverage of sites by building forms. The growth was concentrated in and around the institutional and commercial centres in al-Rusafa, while the urban development in al-Karkh was less crowded and characterized by long winding streets and blocks as well as a low coverage of sites by building forms (Alobaydi and Rashid 2015). In addition, irregular roads and lanes were distributed outside the limits of Old Baghdad in line with the course of the river for use by farmers (who controlled large chunk of lands outside the city) and traders, who had often participated with local inhabitants in seasonal trading activities at the main gates of the city.

- Integration core: As shown in the figure, the integration core of the axial map of the first phase of Baghdad formed a tree pattern. The core was located in the al-Rusafa side. With the exception of the old bridge on the Tigris River, streets with a high value of accessibility were longer streets in denser organic historic clusters. Major institutional and commercial centres of Baghdad were located along these streets. The segregated areas included the peripheral roads at the perimeters of the city wall in al-Rusafa and al-Karkh sides. (Figure 2)

- Choice core: Unlike the integration core, the choice core of the segment map formed a linear pattern. The choice core is represented by the main bridge that connected the two main sides of the city, al-Rusafa and al-Karkh. In addition, most of other streets with high choice values were located in the al-Rusafa side. The segment map also indicates that streets with high choice values were also the streets with high integration values. (Figure 2)
3.2. SUPERGRID AND LINEAR PATTERNS

The supergrid configurational pattern of integration and choice cores is considered as a main feature of the second and third study phases (1920s and 1940s) of the city of Baghdad (see Figure 3). The supergrid in these phases was formed by a set of orthogonal streets, founded by the British Colonial power. This pattern was concentrated in the al-Rusafa side, which already had a dense pattern of everyday interaction, transaction, and encounter (Al-Ashab 1974). Under the rule of the Iraqi Monarchy and the British Mandate, more changes were made to the city by Western architects and planners, using gridded streets, railways, rectangular plots, land use zoning, and concrete buildings (Pieri 2008). These changes helped to form the aforementioned supergrid. This supergrid primarily was formed to control and manage the movement of pedestrians and automobiles within the historic organic residential fabrics characterized by zigzag roads, alleys, and cul-de-sacs. Many institutional, commercial, and mixed-use activities were located along the streets forming the grid. These streets were laid out and distributed in a way that helped to guide the growth of the city in line with the river, from the northwest to the southeast direction.

- **Integration core**: The axial maps of the second and third historical phases of Baghdad show streets with high integration values forming a supergrid pattern (Figure 3). The majority of integrated streets were located in al-Rusafa. In addition to that, the two bridges (including Shuhada and Ahrar) that connected the al-Rusafa and al-Karkh sides also appeared as integrated paths in the supergrid. The segregated core, however, was divided into two areas: first, in al-Kadhimiya where various sets of short and mid-length irregular streets and lanes were distributed in a scattered manner in and around organic historic clusters. Second, a set of long winding streets were distributed in the Karrada quarter located in the southwest of Old Baghdad. Segregated lines were also distributed in the peripheral large agricultural areas on the southwest and southeast side of Old Baghdad. (see Figure 1)
A STUDY OF THE MORPHOLOGICAL EVOLUTION OF THE URBAN CORES OF BAGHDAD IN THE 19TH AND 20TH CENTURY

Choice core: The segment maps for both phases show that the patterns of choice cores are linear, and are different from each other. In the map of 1920s, the linear pattern was comprised of two main streets with high choice values. The core once again included the old bridge of Baghdad, like the core of the first phase in 1050s. The core also included one of the straightest streets founded by the colonial power in 1920s, currently known as Al-Khulafa St. in Baghdad. The street ran parallel to the course of Tigris River. Notice that the core was located within the limits of Old Baghdad in this phase.

In the map of 1940s, the linear pattern of the core consists of two separate parts: the first part was the Ahrar Bridge, which was founded to connect the al-Rusafa and al-Karkh districts of Old Baghdad. The second part of the core was located outside the limits of Old Baghdad. This part, currently known as Haifa St., was formed in the middle of the al-Karkh and al-Kadhimiya districts to facilitate movement between these districts. (Figure 3)
In summary, the most integrated streets covered the super-blocked grids inside the Old Baghdad, as well as the main bridges that connected the al-Rusafa and al-Karkh districts. In contrast, the streets with the highest choice values were distributed in a linear manner along the main bridges and extended beyond the limits of Old Baghdad, thus facilitating movement by avoiding dense historic organic clusters.

3.3. HYBRID OF SUPERGRID AND FRAGMENTED LINEAR

Hybrid of two different patterns – supergrid and fragmented linear – characterized the integration and choice cores of the fourth phase of Baghdad’s maps. The rectangular large blocks with gridded street patterns have significantly affected the density, pattern, and direction of urban growth of the city of Baghdad (Elsheshawy 2004). For the first time, there was a clear tendency for extending the city outside of the physical boundaries of Old Baghdad. By now, the historic cores (al-Kadhimiya and al-Adhamiyah) had grown in a concentric manner, and had become dense focal points. During the mid-1950s, additional gridded streets were used to connect the historic cores of the city with the larger street system. Although these historic cores were located far from the city centre, their main shopping streets were crowded with pilgrims. These streets were known for their concentration of religious rituals, luxury goods, and antiques throughout Iraq (Al-Ashab 1974, Alobaydi and Rashid 2015). Different in size and shape, many large rectangular blocks included industrial and institutional activities and were laid out based on the master plan of Doxiadis Associates in the late of the 1950s (Elsheshawy 2004). In addition, four new bridges on the River Tigris were built to connect the two parts of the city - al-Rusafa and al-Karkh.

- **Integration core**: The integration core was formed by two different patterns of streets: supergrid pattern and linear pattern, which were not connected with each other. While the linear pattern was found outside the al-Karkh district and close to the area known as the Green Zone (GZ) nowadays, the supergrid pattern was found in the al-Rusafa and al-Karkh district. The linear street pattern in the map included the longest and straightest road that was built during the urban renewal projects of mid-1960s (Al-Ashab 1974). Within the supergrid pattern, different types of regular and semi-regular rectangular blocks were included along the course of the Tigris River.

- **Choice core**: The choice core of this phase was different in form and location from the linear patterns in the previous urban choice cores. It consists of two long parts: the first one appeared in al-Rusafa district and continued outside the limits of Old Baghdad along Mohamed al-Qasim Expressway. The second part, similar to the third phase, included parts of Haifa St. between the al-Karkh and al-Kadhimiya districts (Figure 4).

3.4. HYBRID OF LINEAR, SUPERGRID, AND TREE

In the last two phases of Baghdad, the size of the metropolitan city is huge, and the integration and choice cores are more complex than they were in the previous historical phases. They show different hybrid patterns. While the choice core is homogeneously distributed over the whole metropolitan area, the integration core remains concentrated in the al-Rusafa side of the area, particularly around the highway of Channel Army. The River Tigris and the Channel Army now divide the city into three main urbanized areas: 1) Western districts of the Tigris River, 2) Districts located between the Tigris River and the Channel Army, and 3) Eastern districts of the Channel Army (Figure 1), affecting the patterns of the integration and choice cores.

First, with the exception of few remaining organic neighbourhoods in al-Karkh and al-Kadhimiya, most of the western district areas are characterized by widely spaced gridded streets with
A STUDY OF THE MORPHOLOGICAL EVOLUTION OF THE URBAN CORES OF BAGHDAD IN THE 19TH AND 20TH CENTURY

four-way lanes and roundabout intersections, large rectangular blocks, and land parcels often dedicated for residential and institutional activities. Many monumental landmarks, palaces, and memorial parks, reflect a sense of prosperity in these areas as well.

Second, most of historic organic fabrics of al-Rusafa and al-Adhamiyah have been modified by modern planning practices. Many multi-story concrete buildings serving commercial and institutional functions have been inserted in these areas in a scattered manner.

Third, a pattern of rigid rectangular blocks is the main feature of the neighbourhoods and districts on the east of Channel Army. The population of these neighbourhoods and districts often represent middle and lower classes, and are rural migrants who moved from the middle and southern regions of Iraq during the mid-1970s and after (Al-Ashab 1974).

• Integration core: A brief look at the axial map of the last two phases of Baghdad reveal an integration core with three different patterns – linear, supergrid, and tree.

The linear pattern is represented by Channel Army (Figure 1), which is the most integrated street in the axial map. Some of the most integrated streets run parallel to Channel Army while others run perpendicular to it.

The supergrid pattern includes streets with high values of integration that partially overlap with the Channel Army. These integrated streets are found around commercial and mixed-use activities in Old Baghdad and its neighbouring regions.

Finally, the tree pattern includes streets with high integration values in the western districts of the Tigris River. This pattern is found close to the GZ and al-Karkh regions, and is connected with Channel Army by a long winding street named 14th July Street along the northwest edges of the city. 14th July Street intersects with other highly integrated streets, such as al-Kadhim Street, 14th Ramadan Street, Rabie Street, Damascus Street, and Yunis Street in a tree-like pattern. In addition, this pattern is connected to the traditional commercial fabrics found in al-Rusafa by the Shuhada and Ahrar bridges. These two bridges facilitate the movement of goods and people between the integrated streets of the tree-like pattern on both sides of the river.

Figure 4 - the maps of Baghdad syntactic urban cores in 1960s
The segregation core with poorly integrated streets includes two separate parts that covered agricultural areas in the southeast of the city. One part, in the southern district of Karb De Gla, includes a set of zigzag streets and small twisted lanes, influenced by topography. The other part, located in a peninsula in Rustamiyah, includes a complex set of small streets and dirt lanes (Figure 5).

- **Choice core:** Similar to the integration core, the choice core of the two phases consists of three main patterns: linear, supergrid, and tree. Most of the streets in the core are represented by highways and main boulevards that often define the boundaries of quarters (also see Rashid and Alobaydi 2015). The streets of the linear pattern include Channel Army and Dora Expressway during 1980s, while the linear pattern includes Channel Army and

![Figure 5 - the maps of Baghdad syntactic urban cores in 1980s and 2000s](image)
Pluto Road located in the northwest during 2000s. The segment maps show that the streets with high integration values in the supergrid and tree patterns are mostly the same streets with high choice values (Figure 5).

4. CONCLUSION

This paper examined the expanding syntactic urban cores of Baghdad, from an organic nucleus to a huge metropolitan city, in relation to land uses and modernization practices. It identified different types of syntactic cores: (1) tree, (2) supergrid, (3) hybrid of supergrid and fragmented linear, (4) hybrid of linear, supergrid, and tree. The paper also described the relationship between these syntactic typologies and different land use activities and/or planning practices in six different phases between the early 19th century and the early 20th century.

Based on the findings, it can be concluded that the urban core of the City of Baghdad has experienced significant morphological changes associated with modern planning practices. These planning practices include, but are not limited to, rigid rectilinear grid systems of roads and highways, superblocks, and land use zoning. It can also be concluded that the city has undergone significant restructuring. As a result, the stable relationships between syntactic cores and commercial and/or mixed-uses that formed in the early periods of the 19th century have changed. More importantly, planning practices and norms used between 1960s and 2000s have influenced the form and location of syntactic cores. It is suggested that different patterns of integration and choice syntactic urban cores have played a significant role in connecting different parts of the large metropolitan region of Baghdad.
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ABSTRACT
Economics has come a long way into describing the associations between space and industrial production. Since then, there has been considerable research on regional industrial distribution but not quite as much on how industrial sites organize themselves spatially inside urban spaces. This blunders on the hindrance of relating important economics spatial variables, as metrical distance, transport time and site costs, to morphological properties of self-organized and fragmented urban areas. As such, an economical based understanding of cities industrial distribution and agglomeration spatial patterns is still scarce.

Space syntax methodologies offer interesting alternatives to classical economic models, since its methods enable a complex system approach to main economics and regional studies spatial and morphological variables. Its angular analysis allow the evaluation of topological distances, better suited to city network analyses than traditional locational theories approaches, and centrality measures depicted with this method can distinguish and pinpoint the industrial activity attractors only referred by theoretical economics, which permits a better interpretation of the economic spatial logic inside urban spaces. Therefore, this paper explores these relations between economics locational theories and urban spaces morphological properties, taking as its empirical case the 4th District-Development Corridor industrial area at Porto Alegre/RS, Brazil, which comprehends one of Porto Alegre Metropolitan Region’s (PAMR) main industrial sites.

To demonstrate such relations, the distribution of industrial structures in Porto Alegre’s 4th District-Development Corridor Area was mapped and compared to its spatial network, modelled applying angular analyses. Integration and choice measures, correlated to the Kernel Distribution of industrial agglomerates provided robust evidence to corroborate the hypothesis that industrial land use follows the spatial logic suggested by regional economics locational theories in urban contexts. Global integration and choice measures correlation evidences that industrial activities tend to concentrate near the highest global accessibility areas, and, especially, have a strong dependence relation with most relevant “through-movement” routes in the system. However, the sites are scattered alongside these areas, placed in segments with lower global but high local integration and choice values, which denote a localised “clustering effect” provided by higher value global segments.
The results discussion displayed here suggest that space syntax methodologies can provide relevant theoretical and practical contributions to economics locational theories, since they can depict attributes and effects regarding spatial logic of economic activities distribution in urban contexts, phenomena yet to be described and explored by economic locational theories.

KEYWORDS
Urban Morphology, Space Syntax, Locational Theories, Industrial Sites

1. INTRODUCTION

Theoretical Economics has come a long way into describing how places’ spatial properties relate to locational patterns in economic activities and, particularly, how industrial production sites distribute and organise themselves territorially at regional scale. Although there is considerable research done in the matter, the utmost of economic models, derived from classical geography economics, refer to a variable defined as crucial for the determination of special-economic relations: the metrical distance. This happens, mainly, because the transportation time – a metrical distance dependent variable – configures itself as fundamental in production costs and prices composition, thus, having influence in industrial competitiveness in local, regional and global markets.

Metrical distance first appeared in regional studies as a key variable for industrial locational patterns in Weber’s Theory of Locations of Industries (1929) who elicited that the sole regional factors that had influence on location and distribution of industrial sites were labour and transportation costs. These costs were conditioned to a distance, from the industrial sites, towards a series of discrete points in space representing both inputs – workforce and raw materials – and production distribution areas. According to Weber (1929), industrial sites would locate themselves inside regions that minimize locational costs, orientated by minimal metrical distances amid those referential marks and the placement of industrial plants. This approach suited well the economic abstraction of physical features at regional scale, hence, it was followed by other prominent economists as Lösch (1938) and Isard (1956), who also discoursed about industrial location dynamics. Despite Weber’s (1929) work classical nature, even contemporaneous New Economic Geography models, describing industrial agglomeration and regional growth, such as Fujita and Mori’s (1996), and, Fujita and Thisse’s (2002) maintain metrical distance as a comparative measure in analysis of how economic activities differentiate places at regional level and inform agglomeration processes.

Although metrical distance is one of the binding variables in economics regional analyses, it faces serious hindrances when applied to smaller interconnected heterogeneous systems, such as urban grids at local scale. These limitations became evident on Alonso (1964), and Muth (1969) neoclassical urban models, which applied metrical distance in order to explain location, land use, and site costs dynamics inside cities. Even though these models allow remarkable economic conclusions, providing evidences that industries tend to concentrate themselves near central business districts, they are overmuch limited in spatial forms description and do not contemplate multiscale or multidimensional analyses at urban scale, roughly explaining the attractors involved in industrial spatial distribution. This shortcoming relates to the economics locational theories need of setting discrete referential points in metrical distances and spatial fluxes measurements. Due to modification of productive systems and integration of industrial chains, resulting from the shift towards flexible production models, the increase in number of displacements between origins and destinations makes the efficient establishment of such points through traditional methodologies a demanding task. Added to this, the very fragmented, discontinuous and self-organized configurational structure of urban spaces (PORTUGALLI, 2006) makes it challenging to use an essentially non-network based economic theory to study the interactions between industry and urban.

Attempts to analyse urban and metropolitan areas as complex systems and use different concepts of distance, such as topological, in economic analyses are rare, given the predominance
of classical geography economics models. Still, alternatives to orthodox economic analyses are found in Allen’s (1997) self-organising urban growth attractor’s models, in Boudeville (1972), who applied network topological models to describe industrial polarization processes at regional scale based on Perroux (1955) work, and in Crocco, Ruiz and Cavalcante (2008), which study the relationship between urban-regional space and financial services, through the construction of spatial networks. In addition to those, other cross-disciplinary studies have been developed, such as Chiarardia et.al. (2008), which correlates use value and relative accessibility – integration; Roccasalva & Pluviano (2012) analysis, which correlates betweenness centrality to industrial clustering effects; and Yang (2015), which studies the influence of urban networks morphological properties with location and land use through economic big data and space syntax methods and tools. Nevertheless, the need for spatial-statistical analysis non-based integrally on locational economics metrical distance, and an economic driven approach for urban spatial variables through space syntax is still incipient.

Hence, the objective is to display analyses results combining economic locational theories concepts and space syntax methodologies in order to assert if integration and choice measures can depict the logics of industrial agglomeration processes, as stated in regional and urban economic theories. This paper also focuses on describing relations between movement potentials and flow probabilities through urban networks, and industrial activities organization patterns, evaluating “clustering effects” dynamics provided by those both in global and in local scale. The analysis area where industrial land use relations with morphological features are empirically tested is the 4th District-Development Corridor (PDDUA, 2010) area at Porto Alegre/RS, Brazil, which comprehends one of Porto Alegre Metropolitan Region’s (PAMR) main industrial sites, and is undergoing an extensive economic restructuration from the beginning of the 21st century, however conserving some of its old industrial sites.

Findings addressed by space syntax methodologies can lead to innovations on economics locational analysis since they depict the urban network morphological attributes and inform the spatial logic of economic activities diffusion and “clustering effects” in urban contexts, phenomena not yet fully explored and described by urban planning and economics locational theories.

2. DATASETS AND METHODS

To appraise relations between economics locational theories and space syntax methodologies it was apposed two main sets of data on a GIS (QGIS, 2016) database: Porto Alegre’s industrial sites locations and its road network decomposed in an angular segment map.

Industrial sites locations encompasses all industrial dedicated structures located within the Porto Alegre’s 4th District-Development Corridor perimeter. Composed by old industrial neighbourhoods in process of productive restructuration (4th District) and by the modern industrial metropolitan pole, enacted by 2010’s master plan inside the Development Corridor (PDDUA, 2010), this analysis area corresponds to one of PAMR most industrialized regions. This area also incorporates main interstate highways (BR-101, BR-290 and BR-448) and important local A-Roads that cross Porto Alegre northern periphery, being representative to regional transport networks and road structuration. Regarding the locational data gathering for the industrial sites, its accuracy was achieved by comparison between empirical collected data, Porto Alegre’s Land Use and Zoning Map (2010) and satellite data (Google Maps, 2016), mapped altogether in a single polygon shape database. These polygons also contain information about the constructed area of each structure, which is used as a weighting variable in employed geo-statistical analyses.

Porto Alegre’s road network was based on Rigatti & Zampieri (2011) axial map, which was updated by Gambim (2014) in order to incorporate recent urban sprawl patterns, and further converted in segments for proper angular analyses. The once axial map was also partially reconstructed in 4th District-Development Corridor areas using road-centre line representation based on Turner (2007), in order to refine the angular analysis modelling (HILLIER, 2007). This partial adaptation towards road-centre line was made because method’s finer portrayal of choice measurements.
in angular analysis (TURNER, 2001; 2007), which captures represent differences in movement potentials and flow probabilities at a block level better than simple axial lines. In addition, this method can minimize any edge effects in global integration analysis (TURNER, 2001; 2007), which is important as most of the analysis area is close to the system’s border.

Integration and choice measures were analysed globally (radius n) and locally (radius R7 step) in order to describe urban grid topological distances and morphological patterns within the 4th District-Development Corridor Area. Using integration and choice analyses at R7 step, instead of traditional R3 step (HILLIER, 2007), justifies because the mean depth differences among Porto Alegre north (orthogonal grid) and south (discontinued grid) areas are remarkable and only R7 step is capable of revealing the unevenness of sprawl and growth between these two city sectors (BRAGA, 2014). As well, R7 step consists in the last topological radius capable of depicting local centres, without confining the highest segments to areas with predominant orthogonal grid patterns, before the results approximate to global radius (Rn), thus, providing, for these analyses a better spatial logic description. Both global and local analyses have its representations restricted to determined percentiles – which depict the highest value segments for each analysis – intending to establish a parameter for the statistical correlation made through geo-statistical analysis. The calculation of these percentiles, nevertheless, is not arbitrary, and follows a logic proposed in Pareto Distribution Principle or Pareto’s Law (PARETO, 1971), where, in order to be a significant correlation, at least 20% of causes – represented by segment values in angular analysis – needs to be responsible for at least 80% of the effects – determined by industrial structures locations. Such correlation basis established by Pareto (1971), however, is reducible to higher percentiles, in pursuance of establish more robust and precise correlations between cause and effect. The empirical analyses developed use, in addition to Pareto’s percentiles above 80th (20%), to assess base correlations, percentiles above the 95th (5%), in order to halve the 10% correlation spectrum previously used by Roccasalva & Pluviano (2012) and verify in a more detailed way correspondences between industrial organization and urban morphology. Tables below demonstrate the first above percentile values in each angular analysis.

<table>
<thead>
<tr>
<th>Total Number of Segments</th>
<th>Segment Value in 20% Integration – Rn</th>
<th>Segment Value in 20% Integration - R7</th>
<th>Segment Value in 20% Choice – Rn</th>
<th>Segment Value in 20% Choice – R7</th>
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</thead>
<tbody>
<tr>
<td>66627</td>
<td>5.613,47</td>
<td>68,97</td>
<td>2.179.892</td>
<td>830,00</td>
</tr>
</tbody>
</table>

Table 1 - Total number of segments in angular analysis and value of first segment above 80th percentile – top 20% (Pareto Distribution) for integration and choice

<table>
<thead>
<tr>
<th>Total Number of Segments</th>
<th>Segment Value in 5% Integration – Rn</th>
<th>Segment Value in 5% Integration - R7</th>
<th>Segment Value in 5% Choice – Rn</th>
<th>Segment Value in 5% Choice – R7</th>
</tr>
</thead>
<tbody>
<tr>
<td>66627</td>
<td>6.214,79</td>
<td>89,35</td>
<td>31.794,504,00</td>
<td>1.551,00</td>
</tr>
</tbody>
</table>

Table 2 - Total number of segments in angular analysis and value of first segment above 95th percentile – top 5% for integration and choice
THE MORPHOLOGY OF PORTO ALEGRE’S INDUSTRIAL DISTRICT: Between economics locational theories and space syntax methodologies

Figure 1 - Porto Alegre’s Angular Segment Map and 4th District-Development Corridor Analysis Area
Space Syntax Angular Analyses, as depicted, were combined and overlayed with a geostatistical spatial diffusion analysis based on the Kernel Distribution Method (WAND & JONES 1995; BAILEY & GATRELL, 1995), in order to establish correlations among the morphological features found in urban spaces – represented by integration and choice measures, and the industrial sites organization patterns. Such combination between analyses allow to perceive where urban “attractors” or “gathering axis” are located and to observe where the industrial “clustering effects” happen, permitting an approximation to dynamics proposed by economics locational theories.

The Kernel Distribution Method, or Kernel Density Estimation, consists in a non-parametric approach to estimate spatial density functions of a variable within determined areas. Thus, it permits to visualise variables patterns and tendencies on spatial distribution, agglomeration and diffusion potential, resorting to a finite data sample (MURPHY, 2012). It is possible, implementing this method in a GIS database, to spatialize gathered industrial sites data through a heatmap, which reveals, not only areas with higher structures density – denoting industrial agglomeration patterns – but also, assess the probability of diffusion and coverage of these structures, depicted from a metrical distance based radius – or buffer. As such, this method can be employed as a means to evaluate the industrial clustering dependence – on terms of nearness – of the circulation network it is embed, establishing its “attractors” through the correlation with movement potentials (integration) and flow probabilities (choice), denoting consequential “clustering effects” of each configuration at different scales.

The Kernel Estimation used in these empirical analyses is modelled through an Epanechnikov (1969) function, which possesses a minimum variance, leading to improved results on spatial diffusion and density measures. The metrical radii are set at 500m (R500) – the average intra-industrial short displacement routes distance – from the industrial sites polygon centroids weighted by industrial structure constructed area. Although using centroids is not ideal, because it underestimates the diffusion radius and influence span, as it does not irradiate the radius from the polygon form but from its centre, it was the best possible approach allowing spatial analyses, since QGIS (2016) software do not accomplish polygonal based Kernel Estimation.

3. RESULTS

Analyses results indicate the existence of robust geo-statistical correlations between industrial activity organization and distribution, and the urban network morphological properties visualised through integration and choice measures, both at local and global scales.

Those results demonstrate that the industrial sites are rather associated with closeness centralities, with its locational tendencies related to high global and local integration routes, denoting a somewhat significant reliance on the movement potentials provided by spaces with higher relative accessibility. This reinforces spatial vicinity logic in the formation of industrial agglomerations inside urban spaces, as stated by economics locational theories, since it explains intra-industrial and regional movements’ dynamics, and its relations with supportive activities such as retail and services. As well, those findings are related to industrial activities diffusion patterns, as integration is suggested to have a place in the initial development of the industrial spaces.

On the other hand, results regarding choice measures denote that industrial sites locations are remarkably dependent of betweenness centralities, with locational tendencies presenting correlations with high flow probabilities at global and local scales, each one denoting a specific configurational logic. Global results emphasises city’s supergrid relevance concerning industrial sites organization, as these road segments function as “gathering axis” conducing the industrial polarization processes within city, being responsible for main industrial “clustering effects”, as proposed by economics locational theories. Results at a local scale, however, unveil industrial sites tendencies to form “enclaves” places with high local flow probabilities that tend to be segregated from main urban traffic. Such places favour short displacements within industrial sites, providing a reduction on travel time and increasing production chains movement efficiency. As a result, this, alongside the spatial vicinity logic, leads to diminishing costs on production, higher productivity, and local “clustering effects”
Angular Segmented Circulation Network and Kernel Estimation Analysis

<table>
<thead>
<tr>
<th>Integration Rn (Top 20% Segments)</th>
<th>Total - Industrial Sites</th>
<th>Industrial Sites - Within 500m Radius</th>
<th>Industrial Sites - Outside 500m Radius</th>
<th>Correlation - Angular Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integration Rn (Top 5% Segments)</td>
<td>1851</td>
<td>1551</td>
<td>300</td>
<td>83.8%</td>
</tr>
<tr>
<td>Integration R7 (Top 20% Segments)</td>
<td>1851</td>
<td>1840</td>
<td>11</td>
<td>99.4%</td>
</tr>
<tr>
<td>Integration R7 (Top 5% Segments)</td>
<td>1851</td>
<td>1521</td>
<td>330</td>
<td>82.2%</td>
</tr>
</tbody>
</table>

Table 3 - Total number of industrial sites; Number of industrial sites within and outside Kernel Estimation 500m radius of at least one route segment above specified percentile (20% and 5%); And Correlation between Integration Angular Analyses and Industrial Sites Location.

Global integration analysis (Fig.2) establish that 83.8% (Table 3) of industrial sites total are located within 500m from at least one top 20% route segment, revealing the existence of a Paretian (1971) cause-effect correlation between high relative accessibility and tendencies of industrial distribution and organization at a global level. However, when a more restrictive percentile is applied to global integration analysis (Fig.3), it is revealed that only 55.4% (Table 3) of the industrial sites are located within 500m of at least one top 5% route segment, a rather small correlation if compared with the Paretian results, being 28.4 p.p. lower. Furthermore, it can be observed that those recurrences in top 5% happen in areas adjacent to highest global accessibility fringes, far from the most integrated segments within the restriction and from the relative accessibility core. Such analysis demonstrate that high global integration may have a lesser importance as an industrial “clustering effect” factor than once anticipated. Nonetheless, the larger industrial agglomerations (indicated by darker spots in Kernel Estimative) that are found in between integrated segments, corresponding to the aged industrial area, suggest that “to-movement” areas may function as industrial “attractors” in the early stages of its development. This corroborates neoclassic urban economics proposition about industrial location and land use (ALONSO, 1964; MUTH, 1969), as the spatial logic found on network analysis through geo-statistical methods is similar to that theoretically implied in those models.

Local integration analyses indicates that industries have a more complex relation with closeness centralities than global analyses can effectively evaluate. Paretian analysis (Fig 4.) reveal that 99.4% (Table 3) of total industrial sites are located within 500m from at least one top 20% route segment, indicating a robust cause-effect relation between tendencies of industrial sites distribution and the most integrated segments at a local scale, well above Paretian Distribution (1971) established bias. With this correlation, it is possible to explain the movement dynamics and spatial logic vicinity within industrial areas, as presupposed by economic theories. Higher local accessibility conditions implicate in efficient transport routes inside industrial areas, diminishing transport costs and improving firm’s productivity (PORTER, 1998), which leads to a more clustered and interdependent organization in these areas. Is noteworthy, however, that local areas with greater local integration values are infrequently occupied by industrial sites, as observed through Kernel Estimative darker spots absence near R7 step integration cores. Those local integration cores – found on orthogonal grid areas – are generally committed to retail and services activities (ALONSO, 1064; YANG, 2015), that demand more public displacements and visibility, thus, a higher relative accessibility. Such locational predispositions of industrial sites can be better observed through application of a restrictive percentile on local integration analysis (Fig.5), which reveals that 83.2% (Table 3) of total industrial sites are located within 500m of at least one top 5% route segment. Although presenting a high correlation, reinforcing the Paretian findings, the a significant difference of 16.6 p.p, demonstrates that industrial placements are high within mid-range local integration areas, which, in general, also have a lesser land value (CHIARARDIA, et.al 2008), being more attractive to area intensive industrial
activities. The spatial logic found in local integration analyses concurs with Isard’s (1956) patterns of industrial locations regarding transportation, with Alonso (1964) and Muth (1969) economics statements on urban industrial distribution, and with Yang (2015) functional locational patterns.

Figure 2 - Integration Rn angular analysis (top 20% segments) and Porto Alegre's industrial sites kernel distribution (500 m radius)
THE MORPHOLOGY OF PORTO ALEGRE'S INDUSTRIAL DISTRICT: 
Between economics locational theories and space syntax methodologies

Figure 3 - Integration Rn angular analysis (top 5% segments) and Porto Alegre's industrial sites kernel distribution (500 m radius)
Figure 4 - Integration R7 angular analysis (top 20% segments) and Porto Alegre’s industrial sites kernel distribution (500 m radius)
THE MORPHOLOGY OF PORTO ALEGRE'S INDUSTRIAL DISTRICT:
Between economics locational theories and space syntax methodologies

Figure 5 - Integration R7 angular analysis (top 5% segments) and Porto Alegre's industrial sites kernel distribution (500 m radius)
Angular Segmented Circulation Network and Kernel Estimation Analysis

<table>
<thead>
<tr>
<th></th>
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<td>1851</td>
<td>1530</td>
<td>321</td>
<td>82.7%</td>
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</table>

Table 4 - Total number of industrial sites; Number of industrial sites within and outside Kernel Estimation 500m radius of at least one route segment above specified percentile (20% and 5%); And Correlation between Choice Angular Analyses and Industrial Sites Location.

Global Choice analysis (Fig.6) establish that 97.6% (Table 4) of the industrial sites total are located within 500m of at least one top 20% global “through-movement” route, which constitutes a significant Paretian Correlation (1971). Geo-statistical Kernel Estimative analysis unveil that industrial sites locational tendencies are strictly related to the A-Roads and B-Roads (TURNER, 2009) responsible for the urban structuration of 4th District-Development Corridor area, being enclosed by those routes. It is noteworthy, however, that those road segments are mostly composed by the lowest spectrum of choice angular analysis on Paretian correlation (1971), as urban network highest choice segments consists in the A-Roads responsible for connecting city’s north and south areas (Fig.6). Even though this correlation is substantial and capable of explaining industrial sites spatial logic of distribution, regarding its dependence towards segments with high flow probabilities that concentrate industrial transportation routes at an urban scale, it is through a higher percentile restriction analysis that regional dynamics between economic and configurational became discernible. When restricted to a higher percentile, global choice geo-statistical analysis (Fig.7) indicates that 80% (Table 4) of all industrial sites are located within 500m of top 5% global choice segments. These segments accurately represent city’s supergrid, composed by Interstate Highways and main A-Roads within 4th District-Development Corridor area, which function as “gathering axis”, being responsible for the transportation outside industrial area towards Porto Alegre’s Metropolitan Region. These high flow probability roads, as observed through Kernel Estimation analysis, conduce the industrial polarization processes within city, indicating that industrial agglomerations and clusters tend to emerge in its vicinities, in a logic similar as proposed in Allen (1995) urban evolution model, being responsible for main industrial “clustering effects”, as proposed by economics locational theories.

Local choice analysis (Fig.8) also exhibit a high Paretian correlation (1971), as 99.0% (Table 4) of the industrial sites total are located within 500m of at least one top 20% local “through-movement” route. This analysis unveil industrial sites tendencies to form “spatial enclaves”, places with high local flow probabilities that tend to be segregated from main urban traffic. This “enclaves” phenomenon is also supported in a more restricted percentile local choice analysis, which also reveals the connections between industrial sites (Fig.9). This analysis demonstrate that 82.7% (Table 4) of the industrial sites total are located within 500m of at least one top 5% local choice route. Such “spatial enclaves” favour short displacements within industrial sites, providing a reduction on travel time and increasing production chains movement efficiency. As a result, this, alongside the spatial vicinity logic, promoted by high local integration – which even overlays local choice routes – leads to diminishing costs on production, higher productivity, leading to the occurrence of “clustering effects” within urban networks. These findings corroborate Roccasalva & Pluviano (2012) assertions about betweenness centrality as the main morphological attractor in the emergence and conveyance of industrial agglomerations development inside urban spaces, also concurring with theoretical economics proposition about industrial spatial organization dynamics.
Figure 6 - Choice Rn angular analysis (top 20% segments) and Porto Alegre’s industrial sites kernel distribution (500 m radius)
Figure 7 - Choice Rn angular analysis (top 5% segments) and Porto Alegre’s industrial sites kernel distribution (500 m radius)
Figure 8 - Choice R7 angular analysis (top 20% segments) and Porto Alegre's industrial sites kernel distribution (500 m radius)
Figure 9 - Choice R7 angular analysis (top 5% segments) and Porto Alegre’s industrial sites kernel distribution (500 m radius)
4. CONCLUSIONS

Results assessed using geo-statistical analysis along space syntax methods demonstrated significant correlations between urban morphological features and the industrial sites organization, which concur with the industrial activities spatial logic presupposed in economics locational theories and models. Integration and choice measurements are capable to point toward tendencies in industrial sites diffusion and organization, indicating spatial patterns of movement dependence that are followed by industrial development. These measures also explain the relations among morphological features and the “clustering effect” tendencies, demonstrating that main roads—with high closeness and betweenness centralities—can function as “gathering axis” conducing the development and the industrial distribution patterns.

The case study determined that Porto Alegre’s industries locational patterns and diffusion, relate intrinsically to the morphological properties of the urban grid at different scales. Industrial sites tend to locate themselves in the fringes of global closeness centralities, denoting that high global integration and “to-movement” have a minor “clustering effect” factor than once anticipated. These industrial sites, however, are found close to high integration areas at local scale, although away from the integration cores, in regions that favour small displacements in between firms, allowing the creation of efficient transportation routes. Regarding betweenness centralities, industries tend to unveil dependence towards high global “through-movement” routes, corroborating results found by Rocassalva & Pluviano (2012). These areas correspond to the supergrid structure, and conduce regional flows. In addition, it is observed an industrial sites dependence towards local “through-movement” routes, which form “spatial enclaves” segregated from main urban traffic, also favouring short displacements in between firms.

This research, although preliminary, also validates the use of multiscale and multidimensional analysis of spatial dynamics, via combined geo-statistical and space syntax methodology, in economic driven studies, as the correlations needed to attain significance were achieved. In this paper it was asserted that topological distances measured by angular analysis presents itself as feasible “conversions” of traditional metrical distance used by economics locational theories, making conceivable a refined representation of spatial networks morphology for economics analyses. Therefore, it proves itself more reliable – and less complex, as it requires less reference points – than metric distances to depict routes, movement potentials and flow probabilities, that can function as alternatives to represent movement dynamics in economic models. Therefore, incorporating socio-economic data into space syntax modelling presents itself as an interesting development that can lead to innovations in both fields of knowledge, contributing to develop new analysis methods, visualise theoretical presuppositions, and statistically verify relations between cities dynamics and economic phenomena. As such, it also provides evidence that in urban planning strategies must consider, in the creation and development of urban industrial districts, must consider the multiscale analysis of urban and regional spatial network topology, in order to maximise infrastructure investments and provide the basis for true economic development of urban and metropolitan areas.
REFERENCES


ROCCASALVA, G; PLUVIANO, A. 2012 The clustering effect of industrial sites: turning morphology into guidelines for future developments within the Turin metropolitan area. In: Journal of Land Use, Mobility and Environment, pages 7-20


ABSTRACT

Currently, a large part of the world’s population is located in coastal cities and there is a considerable population migration to coastlines areas, once object of seasonal occupation, modifying urbanization patterns in these areas. In Brazilian cities, changes in urban structure due to urbanization and their uneven conurbation processes would tend to cause the loss of the functions and the attractiveness of the historical centres, giving emergency to new centralities. However, as in European cities, it seems that the original urban centres of Brazilian small and medium-sized coastal cities tend to concentrate infrastructure and activities that reinforce their vitality. Therefore, these areas usually attract people and display qualities that support diversified social interactions, and for that, are recognized as symbolic and functional centres of these areas. Thus, this paper aims to describe and analyse the influence of the urban sprawl spatial structure and morphological properties of the Brazilian coastal city of Capão da Canoa in the potential of attractiveness of his original centre and the emergency of new centralities. As a methodological procedure a multiscale analysis based on Space Syntax theory and techniques is realized on global and local levels of the following regions of Capão da Canoa: (1) the original centre of the city, where the occupation of the area has started; (2) the urban centre, which is the most urbanized area of the city; (3) the main district, where the Capão da Canoa resort and the main urban equipment’s of the city are located; and (4) the urban area of Capão da Canoa, which incorporates all the existent resorts and land developments that are part of the city. Different spatial network quantitative data obtained based on two models of analysis – axial and angular - are correlated to land use data empirically collected. Space syntax analysis performed on a GIS database enable to correlate syntactic measures to locational patterns of urban activities in order to identify the correlation between functional and morphological centralities robustness that indicate the emergence of symbolic centralities. The results shows, for example, that the spatial configuration emerging from accelerated urbanization of coastal areas identifies the original centre potential of attraction and its vitality, attesting for the relevance of understanding socio-spatial phenomena driving the production and social appropriation of coastal spaces.
KEYWORDS
Coastal urbanization, urban sprawl, spatial configuration, urban centres, Capão da Canoa

1. INTRODUCTION
Currently, a large part of the world’s population is located in coastal cities and there is a considerable migration of population to coastline areas (Polette, 1997). The interface with the sea qualifies the coastal cities, attracting a large number of users, especially during summer vacations (Moraes, 1999). Therefore, the urban expansion of coastline areas, including small-sized cities, is increasing, which culminates in significant spatial and morphological transformations of these regions. These changes may influence the degree of polarization of the urban centres of these cities and potentiate the emergence of new centralities. Historically, the urban centres are the most important part of the cities, acting as origins of the urban settlements and as the most economically and socially valued sectors, being more likely to support the diversity of uses (Maraschin and Cabral, 2014). In this context, accessibility is a dominant factor, directly influencing the types of activities developed in the central areas. Specifically, the Brazilian urban centres (from which land division in cities is established) tended to be located in the geometric, functional and topological centre of their regions of influence until the middle of the XX century. These were places of greater accessibility relative to the regional and local scale, tending to the expansion of the deformed wheel type, such as European cities (Villaça, 2001).

However, the recent Brazilian urban expansions promoted by private agents according to the market economic interests is characterized by three aspects: the discontinuity of effectively urbanized areas; the expansion of urban perimeters as a form of increasing real estate value; and the dispersion in the infrastructure allocation, following the process of increasing residential segregation (Abramo, 2007). This phenomenon is characterized by the emergence of discontinuous polycentric systems that refer to an archipelago configuration; new centralities emerge at points of greater concentration of infrastructure and activities, in the convergence between regional and local flow, including activities traditionally located in the consolidated centre of the cities (Dias and Trigueiro, 2012). This process affects urban life at various scales and the historic centres, despite their symbolic value, often lose their functions and attractiveness due to the real estate devaluation (Koch, 2005; Read, 2009).

However, the processes of urban expansion of Brazilian small-sized coastal cities present peculiarities in their regional contexts that demand more in depth investigations in order to understand how such urban centres spatially, functionally and economically evolve.

Specifically, the degree of centrality of dispersed and fragmented urban areas, as occurs in the discontinuous and multinucleated occupation of coastal zones, is related to their connection to the road system. A process of land fragmentation is diffused by private and regionally independent agents from this system (Abramo, 2007). The road network is formed on a local scale from the initial urbanization centre and tends to the continuity of the centre-periphery connections; although the discontinuity of the process of land subdivision is evident, the road system is important for the distribution of vehicles movements, attractiveness of the enterprises and vitality of the emerging centralities, which multiply the localized economic investments (van Nes, 2009). The urban centre of the cities, from which the urban sprawl of coastal cities originates, seems to maintain its symbolic functions, related to the process of evolution and development of the coastal urbanization. Moreover, such urban centres have morphological attributes that explain the process of consolidation of spatial configurations from the interaction between the local and global scales (Holanda and Medeiros, 2007).

Therefore, it seems necessary to analyze the different logics of space production and, especially considering the multi-scale circulation systems, how non-exclusive polarities on a regional scale emerge. Thus, this paper aims to describe and analyse the influence of the urban sprawl spatial structure and morphological properties of the Brazilian coastal city of Capão da Canoa in the potential of attractiveness of his original centre and the emergency of new centralities.
2. DATASETS AND METHODS

The city of Capão da Canoa (Figure 1) is located in the urban agglomeration of the north coast of Rio Grande do Sul (Brazil). The city is originally characterized by the subdivision, starting in the 1940s, of the beachfront land of former farms. This phenomenon is further accelerated by the emancipation of the city of Capão da Canoa in 1982 from the City of Osorio and by road investments in the region like the construction of the RS-389 Road. These aspects gave rise to the current districts (Figure 2) in the form of sub-centralities (Santos, 2005). The city is now composed of twelve resorts located in four districts (Capão da Canoa, Capão Novo, Arroio Teixeira and Curumim) connected by the Paraguassú Avenue (parallel to the seacoast) to the urban centre of the city (Figure 2). Currently, Capão da Canoa is a small city, with about 50 thousand inhabitants, but having a high degree of urbanization and undergoing major transformations, being one of the fastest growing cities in the state of Rio Grande do Sul. Moreover, the region receives around 200 thousand visitors and vacationers during the summer season being of easy access from the Metropolitan Region of Porto Alegre (RMPA) and from the Metropolitan Region of ‘Serra Gaúcha’ (RMSG), which concentrate the majority of the population of the state (IBGE, 2017).

Figure 1 - Location of the city of Capão da Canoa

Note: 1 = Urban Agglomeration of the North Coast; 2 = Metropolitan Region of Porto Alegre (RMPA); 3 = Metropolitan Region of ‘Serra Gaúcha’ (RMSG).
A multiscale syntactic analysis (Hillier and Hanson, 1984) was carried out to understand the degree of polarization of the original centre of Capão da Canoa and the emergence of new centralities in the following spatial and territorial scales (Figure 3): (1) the original centre of the city, where the occupation of the area has started, located in the 1st District of Capão da Canoa, in the most urbanized sector between the seacoast and the Paraguassú Avenue; (2) the urban centre, which is the most urbanized area of the city; (3) the 1st District, where the Capão da Canoa resort and the main urban facilities of the city are located; and (4) the urban area of Capão da Canoa, which incorporates all the existent resorts and real estate developments that are part of the city.

Through the one-dimensional decomposition of the urban network in an axial map, where each street is represented by the fewest and longest lines of sight (Hillier, 1996), two forms of analysis – axial analysis and angular analysis - were carried out using the DepthmapX 0.50 software (Varoudis, 2015). In the axial analysis the space system is modelled as an integration structure providing clear notions of the topological distances of the urban network (Holanda, 2002) being analysed the following measures to achieve the objectives of this research (Hillier and Hanson, 1984): the Mean Depth, that is the number of spaces travelled to move from one system space to another; the Global integration (Rn), that is the level of accessibility of a line and its potential of movement in relation to all other lines in the system being analysed; the Local Integration (R3), which indicates the level of accessibility of a line and its potential of movement in relation to the lines three steps away; and the measures of Global and Local Choice, that globally (all the lines of the system) and locally (only the considered set of lines) reveals the potential of a line to be chosen as part of a path. In addition, the following correlations were performed (Hillier, 1988): intelligibility, which is the result of the correlation between local integration and connectivity (the number of connections in each line or segment); and synergy, which is the result of the correlation between global and local integration.
In the angular analysis the spatial network emerges from the segmentation of the axial map (Turner, 2001). The angular analysis adopted the elimination of angles smaller than 25º (by default) that are not perceived as changes of course and direction in urban navigation and can be assumed as a direct route between points (Hillier, Yang and Turner, 2012). This analysis is used in this research because in a large scale system formed by a linear urban expansion with streets that tends to cross the whole system, as in the case of Capão da Canoa, axial lines are not helpful to detect configurational changes at the street segment level. Therefore, the following measures are considered: Global Integration (Rn) and Local Integration (R3 step) to predict the potential of each segment to be a desired destination; Global and Local Choice to calculate the potential of each segment to be select by pedestrians and drivers as part of their paths.

3. RESULTS

The original city centre (Scale 1; Table 1) has symbolic importance as the origin of Capão da Canoa and represents a small (30 lines) and a compact chess spatial pattern, and a shallow axial system with a low mean depth (2.71) with practically only three steps depth. The high rates of intelligibility (0.79) and synergy (0.94) creates a robust system that reinforces the coopresence of users with different profiles in the original city centre (Table 1). The maximum global integration (Rn; 2.48) and local integration (R3; 2.83) of the axial analysis are concentrated in the two main parallel streets that cross the original centre – Sepé and Guaraci Streets. Moreover, the axial analysis shows that the main perpendicular roads - Tupinambá Street and Rudá and Flávio Boianovski Avenues - also have higher levels of global integration, acting as main channels of movement of residents and strangers to the original centre of Capão da Canoa (Figure 4).
<table>
<thead>
<tr>
<th>ANALYSIS AND CORRELATIONS</th>
<th>SCALE 1</th>
<th>SCALE 2</th>
<th>SCALE 3</th>
<th>SCALE 4</th>
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<tbody>
<tr>
<td></td>
<td>The original Centre</td>
<td>The urban Centre</td>
<td>The District</td>
<td>The City</td>
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<tr>
<td></td>
<td>(30 lines)</td>
<td>(70 lines)</td>
<td>(558 lines)</td>
<td>(909 lines)</td>
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<td>2.71</td>
<td>3.03</td>
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Table 1 - Summary of measures and correlations in the spatial and territorial scales analysed
On the other hand, the lower global (Rn; 1.57) and local (R3; 1.73) mean integration values indicate that there are different centralities through the longer lines of the system. Nonetheless, the segmented analysis shows that the most integrated segments of the system are those located in the most central part of the system. Also, the global and local axial routes choices indicate a greater probability of residents and strangers’ movement in the two main lines: Sepé Street - 241 for global choice, 143 for local choice; Guaraci Street - 227 for global choice and 159 for local choice. These lines concentrate commercial and hotels activities, especially on the segments located in the core of the original centre (Table 1 and Figures 4 and 5).

Figure 4 - Syntax analysis of the original centre of the city

Note: 1 = Sepé Street; 2 = Guaraci Street; 3 = Tupinambá Street; 4 = Rudá Avenue; 5 = Flávio Boianovski Avenue.
Figure 5 - The original city centre and its main urban facilities

Note: Dark grey area rectangle = original city centre; 1 = recreation centre of the city; 2 = segment with commerce in Paraguassú Avenue; 3 = City Hall; 4 = 'Mini Golf' Square; 5 = segment with shops and services in Sepé Street; 6 = Lighthouse Square; 7 = segment with shops and services in Guaraci Street; 8 = street market.

Extending the scale of analysis, it is observed that the urban centre of Capão da Canoa is the most urbanized area of the city and has a shallow system with 70 lines and a mean depth (3.03) that indicates a low deformation in the urban grid, favoring the appropriation of the space by residents and strangers. This configuration is fundamental to strengthen the centrality of this area and the predominant commercial activities in the region, such as shops, restaurants and markets, and services such as real estate agencies, that acts as the economic base of Capão da Canoa. In addition, the intelligibility (0.54) of the urban centre of Capão da Canoa decreases significantly (31.7%) in relation to the original centre (intelligibility = 0.79) while the synergy of the system continues to be high (0.92), decreasing only 2.1% in relation to the original centre of the city (synergy = 0.94), reinforcing the potential of polarization of the original centre (Table 1).
Moreover, the axial analysis shows that the global (Rn; 1.91) and the local (R3; 2.24) mean integration values reinforce each other, indicating strong coherence between the movement at city scale and at the local scale of the neighbourhood (Figure 6). The Paraguassú Avenue (Figure 4) captures the global centrality, having the largest global integration value of the system (3.53) and acting as the main route (1534), connecting to the original centre of the city and to the main local route (757). In addition, this Avenue has the highest local Integration value (R3; 3.53), favouring the coopresence of residents and strangers and the establishment of shops and services along its extension. These results tend to be repeated in the angular analysis (Table 1 and Figure 6). The Beira-Mar Avenue also has high global (Rn; 2.83) and local integration (R3; 3.20) values revealed by the axial analysis, been the main access to the waterfront area, where the largest pedestrians and vehicles movements are concentrated. This is one of the reasons why this avenue and adjacent streets concentrates the tallest buildings (up to 12 storeys high) and the highest density developments of the city.

As revealed by the angular analysis (R3step), the local integration shows, that there is also a formation of two local centralities, one to the south and one to the north of the original city centre. These areas have been recently urbanized with a predominance of 12 storey blocks of flats (Figures 6 and 7) and small local shops, directing residents to shop in the original city centre or along Paraguassú Avenue. However, these blocks of flats tend to be occupied only during vacation periods, culminating in a large number of vacant flats during the year and negatively influencing the movement of people in the original centre of Capão da Canoa. Additionally, these buildings are located in peripheral areas of the urban centre. These blocks of flats and the more segregated location from the original city centre are in tune with the profile of users with higher purchasing power who tend to choose such flats for greater security (especially in the south local centrality due to the proximity of the police station), individuality and privacy, and the fact that they do not use public space frequently. In addition, even with the proximity to the sea and the existence of well-maintained squares in the vicinity of these buildings, residents often prefer to enjoy the vertical condominium facilities.
Thus, as allowed by the current master plans (Capão da Canoa, 2004), an intense morphological transformation is observed in the urban centre of Capão da Canoa characterized by the construction of high-rise buildings. Moreover, there is a tendency that these tall buildings will expand to the central areas, to areas near to other resorts waterfronts in Capão da Canoa and in neighboring cities due to the demands of the real estate market.

The urban centre is located in the 1st District of Capão da Canoa, the largest of the four districts of the city with 558 lines and a shallow system due to the low deformation of the predominantly orthogonal urban grid. This system has a mean depth (7.79) that is lower than the mean depth of the urban centre (3.03) and of the original city centre (2.71). Consequently, the intelligibility (0.20) decreases significantly, 63.4% lower than the urban centre and 75% lower than the original centre. The synergy value (0.60) still indicates a robust system, suggesting the permanence of diverse co-presence of residents and strangers. On the other hand, this synergy value is 34.8% smaller than the synergy value of the urbanized area of the city and 36.2% smaller than the synergy of the original centre, what highlights the degree of polarization of the original centre (Table 1). Furthermore, the mean global integration value ($R_n$; 1.06) shown by the axial analysis is also smaller than the mean global integration values of the urban centre of the city ($R_n$; 1.91) and of the original centre ($R_n$; 1.57); this shows that the ring system comprising these areas reflects the coherence of the location of the functional and symbolic centre which originated Capão da Canoa due to the greater level of accessibility to this area (Figure 8).
While the level of local control tends to remain the same, with a mean local integration (R3) value of 2.11 revealed by the axial analysis, the lines with the highest global integration values (Rn) are those representing the main accesses to the city, including part of the RS-389 Road and of the Paraguassú Avenue. In a system tending to orthogonal grid hegemony, this avenue functions as a generator of centrality, concentrating shops and services, the main urban facilities (e.g., city hall, bus station, police station, and airport) and the greatest pedestrians and vehicles movement (Figure 9). Thus, the area between Paraguassú Avenue and the seaside, which encompasses the original and the urban centres of the city, has a more global centre, aimed at residents and mainly at vacationers.

On the other hand, the characteristic “edge effect” of the orthogonal grid highlights the spatial segregation at the limits of the urban system, and the “patchwork” effect resulting from the private management of the urban land. In these areas the real estate sector stimulates the construction of gated communities, which has become a striking feature of the urban expansion of the city of Capão da Canoa (Figure 9). Aimed at users with higher purchasing power and located in the peripheral areas close to the main access road to the city (RS-389), these gated communities are connected by streets with high global integration values and so, that favour the rapid access to these places.

These gated communities are surrounded by walls and have access control with the aim of offering greater security to its residents, emphasizing its spatial segregation in the system. These communities also have a wide range of recreational facilities such as squares, swimming pools, gym, artificial beaches, shops and restaurants, so that residents do not need to leave the walled gated condominium to participate in leisure activities. Additionally, local shops begin to appear on the main access routes to these gated communities, reducing the need for their residents to travel long distances to the original city centre or to Paraguassú Avenue. Besides, these residents usually prioritize the use of the car, which facilitates the trips to neighbouring cities centres.
Thus, as occurs with the high rise buildings, the private spaces of the gated communities tend to negatively influence the pedestrians flow in the original city centre. Nonetheless, these gated communities are already predominant in the 1º District of Capão da Canoa, and tend to increase even more expanding to other districts of the city. Thus, there is a need for greater control of this urban expansion through urban indicators that should be included in the current master plan and other local legislations.

The urban sprawl of the City of Capão da Canoa occurs mainly through the use of the grid model tending to the orthogonal, discontinuous and variable in grain size, in private lots distributed along the seafront. In this context, the intelligibility (0.18) and the synergy (0.51) of the system at the City scale are low due to the discontinuity of the system formed by a fragmented and discontinuous linear urban expansion, resulting in a non-robust system and in social segregation of the city users, reproducing socioeconomic inequalities of daily life also in recreational spaces. Furthermore, the discontinuity of the urban network between the different resorts of the city generates a deep system (mean depth of 10.40) with a low mean global integration (Rn; 0.82), tending to a fishbone, interconnected only by the RS-389 Road and Paraguassú Avenue (Table 1 and Figure 10).
The longest line represents Paraguassú Avenue that is located in the 1st District of Capão da Canoa City has the greatest global (Rn; 1.24) and local integration (R3; 4.05) being the most connected to the old and consolidated urban fabric of the city. Hence, this line favors the movement of residents and strangers and the flow of vehicles in the city and connects the resorts of Capão da Canoa and the city itself to the City of Xangri-lá in the south. The continuity of the Paraguassú Avenue organizes the distribution of the residential plots, resulting in a tree type configuration, capturing the movement and becoming a linear centrality in the city scale. This configuration type favors the local control of constant users (mean local integration - R3 = 2.12), mainly in areas where the orthogonal grid size with reduced grain is maintained, as is the case of the segment with the higher local integration value between the seaside and the Paraguassú Avenue in the District of Capão Novo (Figure 10). Furthermore, through the measure of local integration (R3 step) revealed by the angular analysis it is possible to identify the different resorts (Figure 2) that make up the City of Capão da Canoa and the new centralities that are emerging in the central area of each resort (Figure 10).

In addition, the highest measure of global choice (Rn; 280755) and, mainly, the highest measure of angular global choice (Rn; 12122563) have their routes shifted to the geometric center of the system at Paraguassú Avenue. Unequal allocation of morphological properties between parts.
of the system formed by different resorts of the city give rise to a new type of structure of integration and accessibility due to the process of urban expansion; this causes the dependence of the original urban network in the 1st District of Capão da Canoa to 2nd District of Capão Novo. Thereby, this spatial configuration formed by the urban expansion of the city directly influences the degree of polarization of the original centre of Capão da Canoa and the new centralities that begin to emerge locally in other resorts.

4. CONCLUSIONS

The analysis of the urban sprawl of the coastal city of Capão da Canoa shows that its original centre maintains its centrality and the greatest polarization potential in the various scales considered. The orthogonal grid of the city centre, besides having a symbolic character related to the origins of Capão da Canoa, establishes a main functional hierarchy of the analysed system. These results contradict those which reveal the decay of old centers of other cities and a consequent change of centrality. In the city of João Pessoa (Brazil), for example, it has been notice the transference of bank agencies and notarial offices located in the historical centre to areas that now have more intense movement. This kind of changes attends the market interests, which search for new highly profitable developments as the old city centres decay (Dias and Trigueiro, 2012).

On the other hand, the urban expansion of Capão da Canoa occurs along the waterfront, creating a discontinuity among the resorts of the city, connected only by RS-389 Road and Paraguassú Avenue in a non-distributive system, what weakens the characteristic land subdivision chess pattern. In this context, it is possible to identify the emergence of polarizing new centralities in the street segments where other resorts networks connect to Paraguassú Avenue. These results are supported by the fact, as highlighted by Hillier (2007), that the urban network is formed from the aggregation at the local scale, justifying the importance of multiescalar analysis in space syntax. The continuity of the linear circulation system along the coast is also an intrinsic characteristic of the coastal occupation in Brazil, including that of large cities such as Rio de Janeiro (Azevedo, 1992). The proliferation of high rise buildings next to the beach and gated communities in the periphery of the city also seems to affects the degree of polarization of the original centre of Capão da Canoa. This is related to the fact that these real estate developments are often occupied only temporarily during vacations and are aimed for a certain type of user, that prefers privacy and to avoid the use of the public open spaces.

Thus, the research results show that the centralities are related to configurational and non-configurational parameters, been directly affected by the morphological and spatial transformations resulting from the urban expansion of the city. Additionally, it is highlighted the applicability and importance of the multiscale syntactic analysis in relation to the polarization of urban centres, the emergence of new centralities, and concerning the influence of the urban sprawl in such centralities.
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ABSTRACT

The paper explores the relationship between spatial configuration and public spaces vitality in the old centre of Goiânia (Brazil). The morphological approach evaluates barriers and permeability’s in the city’s structure, based on the theory, methodology and tools of the Theory of the Social Logic of Space (Space Syntax), allowing the scrutiny of variables relating urban configuration and vitality in the selected area. The variables which influence people’s movement (therefore contributing to the use and vitality levels found in the old centre) and the correlation between configurational and non-configurational variables are explored and discussed to refine the comprehension of vitality, so that the role of configuration can be better understood. The two research questions posed in the study are: 1) how does urban configuration, in its global and local levels, affect vitality in the old centre of Goiânia?, and 2) which are the spatial mechanisms which allow the maintenance of urban vitality in old centres? Results have demonstrated that urban configuration affects people flow, reducing or promoting co-presence, in addition to interfering in the vitality and the creation of empty areas. Moreover, vitality is directly dependent on the number of doors that open onto the streets, sidewalks and squares. Land use also plays a major role in the top zones with high number of people according to counting strategies. Finally, vitality is also a product of the urban system as a role. Findings suggest how Space Syntax procedures are helpful to the comprehension of morphological features as promoters of a more diverse and dynamic public space.

KEYWORDS

Old centres, centrality, configuration, vitality, Brazilian cities

1. INTRODUCTION

The relation between spatial configuration and vitality in the old centre of Goiânia is analyzed from a configurational standpoint, which corresponds to the interpretation of relations arising from the arrangements between fulls (barriers) and voids (empty spaces) that constitute the structure of the city and that affect life in the public spaces. According to Trigueiro and Teixeira (2011, p.6):

Configuration is defined by the form and arrangement of barriers and accesses. Barriers are everything that prevent or hinder the passage between spaces or voids (blocks, buildings, etc.); access is what grants passage or permeability between barriers (roads, squares, plazas, empty spaces).

URBAN CONFIGURATION AND PUBLIC SPACES VITALITY IN THE OLD CENTRE OF GOIÂNIA (BRAZIL)
Holanda (2013) discusses the barriers and accesses - or permeabilities - applied to urban spaces, stating that the configuration of these elements can promote the encountering and create more usable spaces. The opposite may also occur, encouraging avoidances and generating idle or unusable spaces.

According to the author, the barriers and accesses interfere in the flow of people and generate patterns of movement, which can be interpreted and quantified by means of Theory of Social Logic of Space, also known as Spatial Syntax, in which Hillier et al. (1993) refer to as natural movement.

According to Saboya (2010), based on Hillier’s studies, “configuration of the urban network”, for example, “has the property of privileging some spaces in relation to others, with respect to the passing movement”. Therefore, the layout of streets would be the main generator of these patterns. It is thus possible to infer that the layout of streets is of fundamental importance for locating uses, especially in central areas that depend on the flow of people.

Holanda (2013) adds that in the case of old centres, however, the layout is not enough to maintain the uses: it is necessary to employ “all incentive mechanisms, so that the occupation is not sporadic, either in space, or time”. When such incentives are not applied, the space of old centres tend to be emptier in certain times of the day, or even completely ‘dead’ at night, as the author observed. He concludes that it is the continuous appropriation that fosters the vitality of the old centres.

Holanda (2014) defines the vitality of the centres as being the presence of the mixture of movement and activities, in space and time. Some authors such as Jane Jacobs and Jan Gehl are references on this topic of life in the spaces of the city. Particularly, the studies of Gehl (2013) are of special relevance because they detail tools or strategies that ensure vitality in public spaces. The urban planner prioritizes the human scale and describes planning measures to ensure the quality and use of spaces by people.

The studies of Tenório (2012) and Holanda (2013, 2014) contemplate these aspects and associate them to the strategies explored by Space Syntax. As previously stated, the configuration of spaces has social implications, that is, the way in which its structuring elements relate in space directly influences the appropriation of spaces by people. In her thesis on public spaces, Tenório (2012) points out mechanisms and develops a method to avoid the death of places. In the case of town centres - if the occupation by people is what promotes the vitality of these areas - both Tenório (2012) and Holanda (2013) discuss some mechanisms that ensure flow, such as: 1) street accessibility; 2) mixed uses and activities; 3) and visibility/permeability of commercial buildings.

Based on these premises, the study explores the urban dynamics that affect the old centre of Goiânia and its vitality, with focus on spatial configuration. To do so, the following research questions were posed: 1) how does urban configuration affect vitality in the old centre of Goiânia?, and 2) which are the spatial mechanisms which allow the maintenance of urban vitality in old centres?

The article, based on a Master Dissertation developed by Arrais (2015), is divided into three parts. The first introduces the theme. The second explains the methodology used. The third, finally, presents and discusses the case study, which anticipates the conclusions.

2. DATASETS AND METHODS

The study is based on the Theory of Social Logic of Space or Space Syntax. Proposed by Bill Hiller and Julienne Hanson in the 70s, Syntax encompasses a reflection on the set of rules and principles which structure the urban space, in order to explore the relations between space and society. Space here is understood based on the work of Holanda (2013), in which he states that “we organize it (space) in order to satisfy and reproduce systems of interpersonal encounters”. The author adds that this perspective is based on the premise that ”human spatial organization, be it in the form of settlements, or in the form of buildings, is the establishment of patterns of relations composed essentially of barriers and permeabilities of various kinds” (Holanda, 2002, P.96).
Barriers and permeabilities are the structuring elements of the urban system, which are also called fulls - buildings, blocks - and voids - roads, sidewalks, footpaths. From the point of view of the spatial configuration, these units that form the structure of the city articulate amongst themselves and are interdependent. As these elements are associated, they can favor the movement of people, foster encounters, provide attractions for specific areas, but also lead to avoidances and render some areas less attractive than others. These questions refer to the potential flow of movement of an urban system.

The Theory of Social Logic of Space works with this systemic perspective for the urban environment and considers that the parts affect the whole and vice versa, demonstrating the existence of an interdependence between the structuring elements of the urban space (Medeiros, 2013). In other words, if a change occurs in the spatial configuration of a certain location, it will affect the system as a whole, in one way or another.

For the present study, changes in spatial configuration that interfere with the flow of movement of the old centre were of special relevance because of the proposed problem. In this sense, Space Syntax was useful because it allowed us to interpret and quantify this movement.

Regarding the tools, axial maps were used and three categories/variables were explored: a) integration (global and local measures from the axial maps), b) permeability of buildings (presence of doors that open onto the streets) and c) land use. The collected data was then faced with d) counting (real movement flow), registered by means of the Gate Method (see “Space Syntax Observation Procedures Manual”).

Procedures considered the counting of vehicles and pedestrians in gates distributed through the old centre of Goiânia (heritage site) (Figure 1), in three zones: Tocantins, Araguaia and Independência. Counting was collected in weekdays (Monday and Tuesdays) and weekends (Saturday and Sunday), in two periods: from 7:30am to 9:30am, and from 5:30pm to 7:30pm (for further details, see Arrais, 2015).

Figure 1 - Identification of gates (The Gate Method) in the old centre of Goiânia (counting procedures), according to specific zones (Tocantins, Araguaia and Independência).
Source: Arrais, 2015.
3. CASE STUDY: THE OLD CENTRE OF GOIÂNIA

3.1. BRIEF HISTORY

Goiânia, built to be the new capital of the state of Goiás, was founded in 1937 and its original layout was planned. Since its conception, the city already presented two main cores: Campinas (an already existing neighboring city to be integrated to the capital) and the area designed by Attilio Corrêa Lima. Before Goiânia was founded, Campinas already concentrated most of the commerce and services, and it was the main active core of the city, while Setor Central was still being consolidated. In the 30s, with the project being implemented, the configuration gradually shifts and Campinas becomes the secondary centre (Alarcón, 2004).

The project of Attilio Corrêa distributed the city in five sectors. The main sector was Setor Central, which concentrated administrative activities in a main square called Praça Cívica and commerce in Avenida Goiás, the main avenue. The streets parallel to the main avenue and Avenida Anhanguera, a transversal axis created by incorporating the old road that connected Leopoldo de Bulhões (another neighboring city) to the former town of Campinas were also mostly commercial. The other four sectors corresponded to their geographical location: Northern Sector, located below Paranaíba Avenue, with a more regular layout and where industrial activities were concentrated; The Southern Sector, destined for residential use; And the East and West Sectors, which in Attilio’s plan are only outlined (Manso, 2001).

The urban expansion of Goiânia in the year 1939 remained within the limits foreseen in the first plan, since the government oversaw the settlement of new areas as a way of maintaining the planned occupation. In the year 1947, the new building code of the municipality made it possible the expansion into new areas headed by the private sector and Goiânia expanded beyond the limits of its original design. The growth took on even greater proportions when, in the early 50’s, the government allowed the construction of neighborhoods without the requirement of a basic infrastructure, only with the establishment of roads. The result was the increase of the urban area, with settlements without basic infrastructure, disconnected and producing numerous urban voids; Constructions without restriction of uses; And invasions in valleys. The city lost its configuration (Ribeiro, 2004).

According to Alarcón (2004), with the increasing concentration of commerce, services and offices, the centre of the city was consolidated as the main core in the 70s. However, from 1980 onwards, the active centrality expanded from Setor Central to Setor Oeste (west), shifting towards the more integrated axes of the urban structure, that is, streets with greater topological accessibility.

According to Correa (2010), the changes that happened in the last decades in Goiânia pulverized some activities and produced new urban centralities. The higher income population of the city lives next to these centralities, namely Setor Oeste, Bueno, Marista, Nova Suíça and Jardim Goiás. Currently, the old centre of Goiânia still concentrates the main activities of commerce and service, despite the urban expansion (Alarcón, 2004). Some public agencies - formerly located in Setor Central - were transferred to other parts of the city, such as the City Hall. The old centre has thus lost its administrative function, but not its performance as an aggregator of various commercial activities and services.

The capital has followed a trend found in other old centres of Brazilian cities that experience the emptying of residential uses and activities and services with an elitist character. This is due to the fact that these centres are seen as degraded spaces and by the offer of areas that supposedly provide better spatial quality. The streets are extremely busy during the day, mostly with people of lower social strata, due to the diversity of activities and services provided, and by the direct contact of the stores with the most accessible streets. The absence of people flow is felt in more segregated streets, such as in alleys and in inner squares, and during the night.
3.2. ANALYSIS: RESULTS AND DISCUSSION

The analysis of the case study focused on the global aspects that involve the system as a whole, and on the local aspects that deal with its structuring elements, focusing on the research problem. At the global level, the study focused on the boundary between Goiânia and the conurbation of Aparecida de Goiânia, in which the aspects of the spatial configuration of the system that affect the old centre were considered. The limits of the old centre are the perimeter created by the buildings considered by the federal government as a historical heritage (Figure 2). Within this cut, routes with different configurations for the application of local variables were selected.

Considering that the movement of people is one of the factors that allows the understanding of the vitality of the public spaces, the research variables were correlated with the real flow of people (pedestrians and vehicle), obtained by the Gate Method (co-presence variable). The results were interpreted using the Cohen scale, adopted in the studies of Medeiros (2013), and complemented with the coefficient of determination $R^2$, according to the procedure suggested by Jacques (2006, apud Medeiros, 2013). According to the author (2013, p.329), this scale is “an auxiliary tool that explains the intensity of ‘r’ from the correspondence between the numerical value obtained (positive or negative) and a range of classifications spreading from ‘nonexistent’ to ‘perfect’” (Table 1).
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<table>
<thead>
<tr>
<th>Category</th>
<th>r</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inexistent</td>
<td>0.0 a 0.09</td>
<td>0.0 a 0.008</td>
</tr>
<tr>
<td>Low</td>
<td>0.1 a 0.29</td>
<td>0.1 a 0.08</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.3 a 0.49</td>
<td>0.9 a 0.24</td>
</tr>
<tr>
<td>High</td>
<td>0.5 a 0.69</td>
<td>0.25 a 0.48</td>
</tr>
<tr>
<td>Very High</td>
<td>0.7 a 0.89</td>
<td>0.49 a 0.80</td>
</tr>
<tr>
<td>Almost perfect</td>
<td>0.9 a 0.99</td>
<td>0.81 a 0.99</td>
</tr>
<tr>
<td>Perfect</td>
<td>1</td>
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</tbody>
</table>

Table 1 - Evaluation of the values of r and R²

For the analysis, Medeiros (2006, p. 283) explains the use of “r” and “R²”:

The value of “r”, or Pearson’s correlation, expresses the degree of relation and/or association between two or more variables. This can be positive (if directly proportional) or negative (if inversely proportional), with values between “1” and “-1” (the closer to “0”, the more fragile the relation is; the closer to “1” or “-1”, the stronger the relation is). R², or coefficient of determination, is obtained by means of a simple regression, which corresponds to the measure of the variability proportion of one variable explained by the variability of the other, being one of the variables independent and the other dependent (or explanatory). The measure is derived from Pearson’s correlation, “r”.

3.2.1 INTEGRATION

In the reading of the Axial Map of Goiânia (Figure 3), it can be observed that the set of more integrated streets (those with greater potential for accessibility - highlighted by the red hues) are distributed over the urban system, in a model called Deformed Wheel by Hillier and Hanson (1984) (apud Medeiros, 2013), in which more integrated streets come from all directions of the city. However, these streets are more evident in the south and southwest part of Goiânia. This set of integrated streets encompasses the old centre, which allows us to infer that the area remains the active centre, that is, where flows and different uses converge, in quantity and diversity. The statement is also reinforced with data on the global integration of its streets, which have shown significant accessibility, even considering the more segregated spaces such as alleys and culs-de-sac.

![Figure 3. Axial map of Goiânia with the reading of global integration Rn for the year 2015. Source: Arrais, 2015.](image-url)
When correlating the integration data of the selected old centre streets with the people count, it is possible to observe that the axes with the highest integration values, for the most part, are also those where the flow of people was more expressive ($R^2 = 47\%$). Figure 4 shows the correlation between the global integration and the pedestrian movement in the centre during the week.

The data reinforce the importance of configuration to attract and sustain the flow of people on the streets. When the analysis is carried out locally, with local integration data, the results are similar ($R^2 = 44\%$), as shown in figure 5.

### 3.2.2 PERMEABILITY OF BUILDINGS

This variable analyzes the permeability of buildings made possible by the presence of doors that open onto the streets. These ‘doors’ can be defined as openings that provide direct passage to the streets. Jacobs (2001) considers these elements as the eyes of the street, fundamental to ensure safety and vitality of the spaces. Holanda (2013) adds that cities need buildings with more ‘eyes’ and less ‘shoulders’ and ‘backs’ to the streets, to favor the encounter between the people. The places of circulation with large blind walls, without ‘eyes’ or doors, are spaces to be avoided by pedestrians, especially due to the lack of safety they instill in people.

In each of the selected streets the number of doors was counted. Initially, the Google Street View© software was used. However, due to the difficulty in visualizing the doors caused by the presence of barriers such as trees and vehicles, the strategy was altered and the counting started to be carried out on site.
In general, considering the results expressed in Figure 6, it is possible to infer that the number of doors along a certain street positively influences the increase in pedestrian flow. Streets with higher number of doors are also those with the highest movement \((R^2 = 59\%)\). Studies show that the possibility of encounters or permeability allowed by these accesses generates a greater sense of security that favors the flow of people, even in situations of closed doors and windows (Barros, 2014).

3.2.3 LAND USE

According to Jane Jacobs (2000) and Frederico de Holanda (2013, 2014), the mixing of uses is essential for maintaining life in public spaces. Considering this reference, the land uses present in each street selected were surveyed, which later allowed the correlation of the types (residential, commercial and mixed) with the number of pedestrians circulating.

Figures 7 to 9, for weekdays, indicate that the flow of people is greater in those streets where commercial use is predominant \((R^2 = 70\%)\). In the context of mixed use (commerce/services with residence), the results also pointed to a correlation that must be mentioned \((R^2 = 27\%)\). In the streets where residential use was prevalent, the movement of pedestrians was lower, with almost no correlation. The data allow us to conclude that for the vitality of the central areas, commercial and mixed use are fundamental. However, these activities must occur continuously in space and time in order to enable the flow of people even after business hours and prevent these areas from becoming completely empty at certain times of the day.
CONCLUSIONS

The research sought to investigate the aspects that affect the vitality in the old centre, in the spatial configuration of Goiânia, based on the changes in the flow of people. Variables pertaining to configuration and land use were applied, which contributed to a better understanding of the problem outlined.

The correlations obtained showed that the variables of integration/accessibility (global and local), permeability of buildings/number of doors and land use tend to affect the number of people present in the centre. These findings, associated with the deeper results develop by Arrais (2015), can contribute to answer the research questions.

Results corroborate the role of the configuration in promoting or restricting a greater urban life (first question). Configuration directs the flow of movement, reduces or promotes the presence of people, which interferes with the vitality in the centre. The study showed that spaces with more integrated configuration (from the point of view of Space Syntax) tend to be more sought after and, therefore, with greater flow of people.

The findings show that the vitality, especially in the public spaces of the centres, is also dependent on the number of doors and the existence of accessible streets /sidewalks, where people also feel invited to stay (an aspect explored in detail in the study developed by Arrais, 2015). In addition, the presence of commerce/services and mixed use is essential to ensure a greater flow. These aspects suggest some spatial mechanisms which allow the maintenance of urban vitality in old centres (second question).
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CAN THE CENTRE-TO-BE BECOME A REAL CENTRE? 
Gdańsk revisited

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ABSTRACT

The historic centre of Gdansk in Poland evolved over the centuries. The decision made at the beginning of the new millennium to incorporate neighbouring former industrial area into the city centre created a new opportunity to investigate the dynamics of central city core. The municipality envisioned the new area to have the liveability of a city centre. This paper investigates this area potential, first by looking at the development of historical centre in 1792, 1933, 2005 and taking into consideration translocation of the integration core to compare the morphological picture with the configurational model’s predictability in respect to pedestrian movement and functional distribution. The research for this part of the study was carried out as a part of PhD thesis ‘Functional performance of space - Gdansk case studies’. The investigation of urban activities has shown how they coexist with movement and to what extent they are correlated with integration potential. Subsequently, four concepts of urban developments of former industrial area (centre-to-be) have been considered, with particular attention to their integration potential and intelligibility analysis, and some recommendations for the revival of the centre-to-be area and for planning process of its integration with existing centre have been formulated. In the second part of the study the question of centrality has been put forward when the case of Gdansk centre has been revisited a few years later to examine how city centre development and first new investments influence urban dynamics.

KEYWORDS
Urban Dynamics, Spatial Integration, Post-Industrial Area

1. INTRODUCTION

What is an urban heart? Can we identify it with an urban centre by definition, planners’ decision, inhabitants’ perception, or according to its liveability? The question about an urban centre brings into attention the notion of centrality. This term is perceived differently depending on the context of discussion (Hillier 1999, Cutini 2003). Urban centrality can be perceived from the historians’ point of view as a central urban area where the historical memory of community and its inhabitants is materialized and expressed. The sociological perception defines the centre as a part of town which is distinct from other areas in terms of institutional infrastructure, urban composition and architecture. At the same time it is the best located and most accessible area - crucial for functioning of urban community where public life takes place. The architectural perspective deals with urban morphology of centres. The regional planning approaches the issue from the functional perspective - taking into account attractiveness, intensity and types of functions located in specific areas.

These definitions do not make it easier to deal with the problem of centrality. They do not specify the problem clearly enough to answer the question about the reasons influencing the primary location of activities in a centre. Why a given place is central? Are land use aspects independent...
of space, or do centres change in response to economic and planning decisions, or are there any underlying spatial processes pushing the development in a specific direction (Hillier 1999)? As B. Hillier (1999) wrote: “centrality is clearly not simply a state, but a process with both spatial and functional aspects”. It means the transition from concentrating on problems of given places towards dealing with spatial characteristics. Therefore we could call the urban heart this part of any urban structure that integrates space and generates the most intense movement.

The reflections on centrality seem to be an essential part of discussions about urbanity nowadays. However, managing the process of centrality proves to be a difficult one. Urban transformations – especially those characteristic for sudden economic and political changes – appear to be overwhelmingly rapid while accompanying planning decisions do not always manage to embrace the complexity of urban reality. The process of transformation of centrally located derelict sites and incorporating them into urban structure can serve as an example. The issue of regeneration and transformation of post-industrial sites for new functions under the conditions of knowledge economy has been extensively dealt with in Western European countries, but it still constitutes a substantial challenge for municipal authorities, developers and urban planners and designers in Poland. It proves to be more complex than it was originally anticipated. Since the transition of the political system from communism into democracy in 1989 new economic conditions enabled urban transformations and since then several sites have been the subject of debates in the search for regeneration process (Stangel 2012). Joining the European Union community in 2005 has given a new impact on these processes as it resulted in the possibility of acquiring European funding substantial to make progress on several Polish projects.

In this paper it is the city of Gdańsk that will be investigated. The decision of incorporating an industrial area into the city centre created a new opportunity to investigate the dynamics of central areas. The municipality envisioned the new area to have the liveability of a city centre. Several questions concerning this new development need to be asked. Will the development of the discussed area reduce the process of disintegration throughout the whole downtown? If so, will the current centre loose its meaning (as a result of shifting the central area) or gain when being extended (as a result of a synergic effect)? Can we say that a new urban centre will be established? Will the new district be locally integrated (internally coherent)?

2. DATASETS AND METHODS

The analysis of the new area potential needs to be seen through the perspective of the development of historical centre of Gdańsk in 1792, 1933 and 2005 taking into consideration the characteristics of translocations of integration core. The results of syntactic analysis are to be compared with the inhabitants’ perception of the city centre and the liveability measured by pedestrian movement and distribution of retail.

Historical evolution of city centre. Gdańsk is a port city of a long historical tradition. In the XVIII and XIX century it used to be the rich merchant city of vibrant multinational population and it belonged to the Hanseatic League. In 1920s and 1930s the city was taken under the protection of the League of Nations. The historical centre of Gdańsk evolved over the centuries. During the last two centuries one can observe a few stages of its development: the historical centre went through the process of discrete transformations of its kidney-like form. Gdańsk in 1792 is the city of a clearly defined area enclosed by the Dutch style fortification system built at the beginning of XVII century. Gdańsk in 1792 is the city of a clearly defined area enclosed by the Dutch style fortification system built at the beginning of XVII century. It has an internal port located on the Motława River to the east of the city centre. Gdańsk in 1933 is the city with dense, highly populated housing, enriched by the new public buildings erected on the city outskirts at the end of XIX century after levelling the fortifications. At the time, as the fortification was no longer a barrier, the urban fabric started to spread. Gdańsk gained a new entry road and the railway arriving to the west of the city centre. Contemporary Gdańsk reconstructed after the war damages was also transformed (the alterations of some streets’ layout), however the urban fabric itself was not entirely filled in. The post-war city centre has been cut in two parts by a busy road (three lines in each direction) separating its southern part (the Old Suburb).
In the contemporary urban structure of Gdańsk it is difficult to delineate the municipality limits. Gdańsk is perceived with the cities of Sopot and Gdynia as one urban organism called Tricity. For the purpose of the research a configurational model was processed in Axman for a bigger area than the administrative limits of Gdańsk (axial map). The syntactic model was elaborated to depict the spatial and functional urban phenomenon in a longer time span. Three characteristic periods of urban form development were analysed. Figure 2 shows that in the model of 1792 the shape of the central area is typical for traditional historic towns. It is characterised by a compact grid covering the area of the historical district called the Main Town. Both the water canal system and the fortifications limit and embrace the urban structure which has a compact shape with a distinct integration core containing key public buildings within its limits. The second map (fig.2) represents the model of Gdańsk in 1933 - the integration core has a more irregular form and seems to change its axis reaching towards the north-south direction. The core moves to the west towards the route parallel to the newly built railway. While at the beginning of the XX century the main part of the integration core with the east and west projections was still located within the Main Town, the 2005 model shows that the integration core is less defined and shifted. It is linear and fragmented: the first stretch has the key importance for road traffic in macro scale; the second one is used as the route connecting the railway station with the historical street called the Royal Route located in the Main Town. Both strips seem to be connected, but in reality they are independent: the meeting point is just a traffic junction.
The transition from the closed and compact integration core to the linear one is a characteristic change in the process of disintegration and dispersion of urban structures as it is the result of incautious layout adjustments and incidental locations of extensive commercial centres (Hillier 1999). This observation proves true for Gdańsk centre. The fragmentation of the integration core is associated with urban development and the city dispersion. It is also possible to observe the drainage of local retail from streets to commercial centres. As the result of opening of two shopping centres next to the railway station, most small shops - situated along a lively street leading to the Main Town - were first closed to be reopened later as banks and restaurants but mainly in the areas of the most intense pedestrian movement.

The inhabitants of Gdańsk associate the most lively and popular element of the Royal Rout in the Main Town as the most important indicator of city identity (Załęcki 2003). They perceive the area depicted as the most integrated part on the map of Gdańsk 1933 as the actual city centre: almost 70 % of the inhabitants identified the centre with this historical area associated with cultural values.

**Liveability of contemporary urban structure.** The configurational analysis has been confronted with pedestrian movement levels to verify the syntactic model’s predictability. Several observations were done for 95 gate points evenly distributed in the city centre in October 2003 when the weather was favorable to walk and it was possible to observe everyday urban dynamics without the holiday activity shifts due to the presence of tourists or special events. It was proved that the model represents well the spacial interrelations: the correlation between movement and integration values was strong (R²=0.85).

The good design practice advocating for urban life described in the literature emphasises the significance of maintaining appropriate levels of movement intensity as a good indicator for urban liveliness (Gehl 1996, Carmona et all 2004). It enhances human-friendly streets and squares as well as creates good conditions for different formal and informal activities. It is indicated to maintain the number of pedestrians at peak hours at the level of 20 persons per minute per meter of pavement width - according to the research in American cities (Whyte 2004). Other research for European cities claims it is enough to provide the half of the number postulated by Whyte that is 10 persons per minute per meter of walking area (Gehl, 1996).

The observations done in off-season period depicting inhabitants’ movement showed two most intensively used spaces in the centre of Gdańsk. The first one is the street next to the subway entrance leading to the railway station - 29 persons per minute. The second space where the
movement of 26 persons per minute can be observed is located along the Royal Route (the Long Street and the Long Market Street). This pavement area of 15 m width has two lines of side cafes therefore the effective walking space is decreased to 7-9 meters. Having taken into account the diminished numbers it appears that the rate of 3 person/min/m does not reach the score postulated by Gehl. However this changes in summer when the flow of foreign tourists and local visitors raises significantly the movement intensity up to 15 persons per minute per 1 m of pavement. The study of city activities and functional distribution has shown how they coexist with movement and to what extent they are correlated with integration values (table 1). The retail distribution follows the logic of integration values within urban centre (strong correlation – 0.764)

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<tr>
<th>Number of retail and shops for every 25 m of street length</th>
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<td>Number of pedestrians per minute</td>
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** p value < 0.01

Table 1 - Correlations between integration, pedestrian movement and retail activity.

Spatial analysis of Young City development. The studied area is located to the north of the existing centre (fig.4). The shipyard site remained industrial till 1995 when the first ideas of reurbanisation were developed following the decision of withdrawing the shipyard activity to the Ostrów Island on the opposite bank of the river (Dead Vistula River). The terrain contains a former shipyard area, gasworks, factories and a bus depot. In Gdańsk there is a tradition of naming historical central districts as ‘towns’ what underlines the separateness and distinctness of each urban part. The new area is promoted as the Young City what seems to relate to this tradition of creating local environment of a ‘town’ (and obliges to fulfill urban standards of integration and liveability on local level) but also accentuates contemporary vibrant characteristics associated with the name ‘city’. Since the begging it has been believed that the new development would give a chance to create a new lively and coherent district (Kochanowski and Kochanowska 2005) serving as a natural extension of the existing city centre.
Design concepts selected for the present analysis were conceived in the years 1996-2000. They were prepared in the first years after the withdrawal of the shipyard and presented a wide scope of approaches to address the possible area development. It is however essential to underline that these discussions were undertaken in the conditions of relatively young democracy acting without any adequate procedures ready to be applied. The development of HafenCity in Hamburg for example was proceeded by several years of planning and preparing consequent urban strategies. In Polish situation it was the sudden deterioration of shipyard economic situation that opened discussions about the release of the industrial site for other urban functions.

The version 1 (fig. 4) is the vision created by architects wishing to restore the historical city plan with its characteristic fortifications. They intended to create the street layout on the perimeter of former bastions providing a strip of green areas as an equivalent of water canals. The area of Young City itself was supposed to be developed on a different grid outside the outlines of the fortification line (Hryniewicz 2000). The options 2 and 3 represent urban strategies that envisaged the Young City as a modern extension of the city centre building the area identity on the basis of existing values (the industrial character and the history of the Solidarity movement). The version 2 follows indications of the Revitalisation Study from 1996 specifying the directions of district development to accommodate housing, retail and leisure with a substantial part dedicated to museums. The idea of unrestricted urban corridors of protected views was underlined there as well as the significance of maintaining the connection between the Solidarity Square and the waterfront via so called . The technical parameters of the main street of the district were specified to create a ring road for the city centre rather than internal district road with several underground passages for pedestrians. The third concept was prepared as the Vision Master Plan in 2000 for developers (Pieprz 2001). It continued basic principles of the version 2 (protected views, waterfront promenades), but it was postulated to introduce a traditional urban block structure and shape the main district road with pedestrian boulevards and traditional street-level crossings. The option 4 is a result of a configurational experiment (see figure 4).
3. RESULTS

The concepts of urban development of the centre-to-be have been considered with particular attention to their integration potential and intelligibility analysis. The analysis of syntactic parameters made it possible to draw some interesting conclusions. In the case of the solution 1 and 2 the users of the Young City would have problems of perceiving the new district as a coherent and intelligible urban structure what signifies wayfinding problems and difficulties in defining the area identity. The area intelligibility (R2) is low (0.24-0.26) what is comparable to results characteristic for criticised modern housing estates. This kind of spatial quality contributes to further urban fragmentation characteristic for architectural urbanity (Marcus 2000). Both solutions will not create the district with its own local integrating core. However, in each case the area development will have a positive impact on city centre seen as a whole. The mean integration values increase (IntRn: from 0.88 to 0.93-0.98, and IntR3: from 1.97 to 2.08-2.18) what can be related to the increase of central urban dynamics.

![Figure 4 - Gdansk - Young City development alternatives (axial map: global integration IntRn)](image)

The solution 2 creates a vivid distinction between the internal part within the heavy traffic road and the external one (relatively segregated). The area would be illegible and incoherent on the local level. The solution 3 creates a district that would be peripheral to the city centre but locally integrated what might enhance a good living environment. Taking into account the potential for enhancing the centrality, the version 4 – an experiment following configurational logic of promoting connections to well integrated streets - achieves the highest values of parameters.

As it is shown in the analysis the urban fabric of the centre of Gdańsk is going to be extended and enriched by a new urban structure but regardless of the planning solution (1-4) the development of the Young City is not going to be reflected in any substantial change or shift in the existing integration core. The only difference within the core is the position of streets located on the
north-east of the train station, close to the Solidarity Square. That area located close to the Young City and former shipyard entrance will become more lively, integrated and attractive for investment. The Young City itself as a whole district is not going to be characterised by spatial measures typical for central areas. It is inclined to have rather low liveability associated with natural movement generated by urban grid itself, what is common for peripheral urban areas. One may expect the mean number of max 1-2 person/min on streets on everyday basis. The waterfront promenade may become popular during cultural events and for weekend walks, but the regular grid-defined movement would oscillate below 1 person/min.

The results of the above analysis demonstrates the area potential in configurational values translated into estimated levels of movement. It underlines the strong and the weak points of the Young City’s position. However these results were not well received by urban planners and designers in 2005 and there was no interest from the city municipality to consider the use of space syntax approach to investigate further the urban potential of this new development. The analysis was claimed to be irrelevant and incomprehensible. It is possible that the results were contradictory to the ideas promoted by planners or politicians. Due to those difficulties the analysis was neither used nor published. However the questions about managing centrality in Gdańsk remained.

The situation of the Young City after 2005. The transformation of the discussed area has been developed according to the guidelines of the revitalization plan represented by the version no 2 which was questioned in this study due to the impact of the main district road on the integrality of the area. The definition of the main district road (the Nowa Wałowa Street) - its position, form and characteristics – stays as a very important factor for the revitalisation of the Young City. Two local development plans were established in 2006 and 2008 and there was a correction of the line of the Nowa Wałowa Street which was slightly moved to the north, creating around the Solidarity Square an area for commercial centres. The change seemed to be an economic decision (postulated by developers) rather than a reconsideration of the district integrity. It was associated with buildings’ demolition but allowed to liberate a vast terrain relatively close to the railway station and designated for commercial galleries. Unfortunately, the characteristics of the Nowa Wałowa Street stayed defined according to separating strategy of the solution 2. The road is planned as four traffic lanes and a tramway line, with a few hundred long embankment, and just two crossings (possibly two more in the form of elevated footbridges or pedestrian underpasses) facilitating passages through the 2 km long street. This solution causes controversy in local social media. As shown in the analysis this potentially attractive district effectively is going to be cut into two parts by the traffic line. The construction of the Nowa Wałowa Street is done in stages what still gives an opportunity for rethinking the anti-urban impact of the present form of this street. Local urban activists and some architects underline a commonly expressed concern about the lack of the sense of identity of Young City as the new development is planned mainly to satisfy economical needs of developers and current proposals for architecture lack any originality of local industrial heritage.

Since 2010 the official discussions concerning the Young City concentrate on presenting future visions of vibrant city. It is a seducing and elegant perspective however the envisaged liveability might become true mainly inside planned commercial centres which does not equal liveable urban street. The district is supposed to contain 3.5 thousand flats and many commercial buildings like three 100 meters high skyscrapers, centre for innovation for business, hotel, conference centre and a huge shopping centre. However till now it is not clear how exactly the Young City is going to look like.

Even though the industrial heritage preservation was declared in urban strategy in 2000, in reality several buildings were left without any protection and some were destroyed. It might be seen as a part of a silent strategy of developers who managed to acquire vast and prominent terrain in the city without any public discussion or sale announcement. Developers seemed to be more interested in the land value itself than in the heritage protection. It is also evident that it is easier to build on the empty terrain than to be restricted by heritage protection requirements. Currently the growing social consciousness and the strong movement of artists promoting the genius loci of shipyard area has succeeded in advocating for the preservation
of crane structures and industrial buildings what was not so obvious ten years ago. The social actions helped to protect several buildings and last shipyard cranes – they are now listed as a part of national industrial heritage.

Architectural micro-interventions. Since 2005 urban dynamics in Gdańsk was stimulated locally by developments of some historical sites. It is much easier to influence urban reality by a micro-intervention aimed at densifying plots’ use. Three interventions concern the areas located on the outskirts of the existing centre of Gdańsk what helps to extend the scope of existing city centre attractions. The municipality invested in promoting the city via cultural buildings meant as architectural icon landmarks. These buildings are important symbols for national or local identity and as such their construction attracted the common attention and the collective willingness for cooperation.

The first architectural icon is the European Solidarity Centre (Fig.5), located next to the entrance to the former Gdańsk Shipyard (at the Solidarity Square) where in 1970 the shipyard workers were killed and where there is a symbolic construction of three crosses called the Monument to the Fallen Shipyard Workers. The international architectural competition was held in 2007 and the opening took place in 2014. The building houses a centre for the ideas of freedom, democracy and solidarity to be fostered as well as the museum and the conference venue. The 5-storey building has the tilting walls reminiscent of a ship’s hull. The building is co-funded by the European Union.

The second architectural icon is the Gdańsk Shakespeare Theatre located to the south, next to the remnants of the city walls of the Main Town (Fig.5). The building was designed as a result of an international competition organized in 2005, on the site of a 17th-century theatre, where English travelling players performed. It was opened in 2014 when the construction became possible due to the EU funds. The building has a brick shell which houses a playhouse structure - the Renaissance wooden theatre with the retractable roof (Limon 2014).

The third architectural icon is the Museum of the Second World War (Fig.5) opened in April 2017. This symbolic space of memory is located on a plot on the bank of the water canal in the southern part of the Young City, 200 m from the historic Polish Post Office in Gdańsk and 3 km across the water from Westerplatte Peninsula, both of which were attacked in September 1939 to begin the Second World War. The building was designed as a result of an international competition hold in 2010 and financed from the state funds. It is described as a unique, powerful icon and a new symbol of Gdańsk and serves as a centre of education, culture and research but also contains the space reserved for the permanent exhibition.

Behind each of these buildings there is a strong iconic idea (solidarity, war, multinational tradition of Gdańsk) that is easy to identify with and ready to promote what is very important in the situation of fund raising. The concepts of creating the European Solidarity Centre and the Museum of the Second World War became an important element of political discussions what influenced the careful choice of prominent sites and the organization of international architectural competitions. The nationally recognised significance of historical events helped to complete the projects regardless of exceeding the primary project budget. This situation demonstrates the important aspect of the Polish reality. City municipalities in Poland are obliged to prove the necessity of a given project to be supported by state funding. The Polish governance system leaves no real economic power to local city municipalities. The income paid in taxes cannot be used by any city itself, it is transferred to the regional governance and later redistributed to local municipalities but only for specific purposes. This situation establishes evident constraints on any strategic urban planning. It allows for punctual interventions but proves it almost impossible to prepare long-term urban development strategies without the cooperation of developers. Municipalities govern cities but stay without real economic power. It means that project goals promoted by city municipality need to be distinct and short-term (possible to accomplish within the period defined by the date of next elections).
Urban micro-intervention. Another example of micro-intervention in Gdańsk is the long discussed idea of a footbridge. Since 2000 there were discussions concerning the accessibility problem of the Ołowianka Island defined in the municipal strategy of urban development as the Cultural Zone (fig.6). This small island on the Motława River used to be an industrial site and now houses the Polish Baltic Philharmonic in an old converted power station complex and the Maritime Museum. In 1997 the first open air concert was held in the amphitheater on the river, but the actual concert hall was opened in 2007 when the financing from EU and city municipality was available. This area is located in the immediate vicinity of the Main Town and the Old Town, but is accessible for visitors mainly by ferry in the opening hours of the Maritime Museum or via a long route leading to a considerable distant bridge on the extension of the Royal Route. Public space on the Ołowianka Isle is well maintained and has a potential to become an attractive place for inhabitants and tourists. However, it is evident that the cultural buildings do not serve as a sufficiently strong magnet to attract people on everyday basis. The place is deserted except for the period of concerts and cultural events. People usually have problems to find the Philharmonic as the access is complicated.
In 2004 the director of the Philharmonic started the public discussion about a footbridge to link the Ołowianka Isle with the Gdańsk Old Town where a parking could have been potentially located. It was believed that the construction of such a bridge would create the possibility of extending the tourist route along the river waterfront what would allow for viewing the Main Town from a new perspective creating a circuit route through the Ołowianka Isle and the marina located on the other side of the Granary Island (see Fig. 5).

The footbridge idea as a possible micro-intervention was verified by the author using syntax analysis. The study explored other alternatives to see which solution is able to meet the expected requirements of bringing life to the island: reviving it and reciprocally enhancing life in the Old Town. What bridge characteristics should be applied to solve the problem of the Ołowianka Isle - visible from the Main Town, but not accessible? The configurational study showed that currently the integration values for individual streets on the island oscillate around 0.65-0.8, while on the other side of the Motława River they reach 1.1-1.2. The number of passing people on the isle could be translated as less than 0.05 person/minute, while on the other side of the river there is an average of 5 persons/minute.

The figure 8 shows four proposals for the footbridge location represented by the point depth map (the closeness of urban grid elements from the island is expressed by changing colours: red is very close, green and blue very distant).
The option no 2 is the proposal of designers from the Department of Bridge Construction in Gdańsk and it was promoted by the director of the Polish Philharmonic in 2005. The structure was supposed to contain a series of elevated ramps ending near an open stage on the Ołowianka Island. The options 1, 3 and 4 were invented for the purpose of comparative analysis. The option no 1 is a link towards the Old Town. The options 3 and 4 propose the extension of streets of the Main Town.

In the case of solution 1 the Ołowianka Island gains a substantial connection with the Old Town. The bridge influences the urban structure enhancing its integration values. The impact of the footbridge in option 2 turns out to be smaller – the isle will seem more segregated. The problem stems mainly from the form of bridge construction. The access via elevated ramps would be more complicated, so less people would spontaneously decide to use it. In both alternatives (no 1 and 2) the local livability measured by local integration values will increase (IntR3 = 1.83-1.84). In the solution no 3 the Ołowianka Island gains a direct access to lively area of the Main Town. This connection creates an impression that the Philharmonic is just right the corner and the areas can benefit mutually. The mean local integration values for the Isle raises significantly (IntRn=2.01). The version 4 is similar (the increase of mean local integration value IntR3=1.908).
The highly promoted solution no 2 was fortunately abandoned. Till early 2010s different alternatives of location and form of river crossing were considered by the city municipality (a tunnel, a ferry or a bridge). Finally, in 2012 the city municipality organised an international competition for the footbridge in the location specified in the solution no 1. It is not clear if the present study had any influence on the choice for the above location. The coincidence might be purely incidental. Even though it is fortunate that the place and the specified landings promoted the good connection with urban grid. The Slovenian company Ponting who won the competition, delivered an elegant and simple point-draw bridge (70m long). The bridge is under construction now and hopefully it will provide a good solution for the urban liveability of the area. The position and simplicity of the crossing with landings at street level on both sides will give an easy access and create an interesting tourist circuit connecting the most integrated Royal Route via the riverfront towards the Museum of Second World War and providing an interesting return to the Main City via the footbridge to the Oł ovarianka Island. The bridge is also going to have a positive impact on the urban grid: it creates a connection between the Young City and the cultural buildings on the Oł ovarianka Island.

4. CONCLUSIONS

The syntactic perspective gave the ground for in-depth study of the Young City potential and the development of Gdańsk centre, however other factors influenced the choice of planning solutions. It would be beneficial to repeat the analysis in the near future when the final planning decisions will be specified as currently there is no substantial amount of data to run analysis for the whole area.

The area did not develop as rapidly and as successfully as it was first envisioned. The obvious economic burden of constructing the main district road and still discussed river crossing that are expensive and time-consuming has an inevitable impact on time and work progress. However the long time span of area development appears to be beneficial for rethinking planning decisions. It is optimistic to observe that eventually some of small developments followed the configurational logic in design decisions as it was presented in the case of the footbridge. The choice might be incidental but it foreshadows the increasing awareness of urban elements impact on city spatial structure and hopefully will give the ground for more careful explorations of different design and planning solutions at least on the level of micro-interventions.

Managing urban centrality is still regarded as the fundamental goal of contemporary spatial development strategies aiming at revitalising city peripheries or reviving historical towns. At the same time the lack of effective management of centrality makes these aims illusory. The
phenomenon of urban transformations is often noticed ex post. It is however interesting to observe the process systematically, or even to anticipate it and cooperate with it. The need of monitoring in the case of minor changes is even more significant. Micro-transformations happen every day. As a result of actions in one place, there are unexpected changes in another, sometimes very distant one. Understanding the process and anticipating what may happen, can help to control spatial dynamics causing shifts in urban core and avoid expensive and irreversible consequences. Unfortunately contemporary focus in Gdańsk is concentrated on acting in macro scale and according to global visions. The new district of Young City risks to lack basic urban features (like a local integration core as its internal centre) necessary to maintain the area identity and distinctiveness.

There is something disturbing in the common conviction that the urban centre is there where one plans it to be. The technological means available today allow for building a city from the scratch anywhere using developers’ implanting strategies that can be called ‘from now on the city is there’. However, the success of investors does not necessary equal working for urban wellbeing. The opening of huge multifunctional commercial complexes in restored industrial areas leaves every city distorted. Such developments suck life from substantial parts of cities. It seems to be not the right urban game to play. The ideas on how the city should look like are supposed to be accompanied by taking the responsibility for the results of their fulfilment.
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ABSTRACT

This paper is part of a wider on-going research project, which intends to contribute with new and comprehensive knowledge about school buildings in Portugal for secondary and middle education under the framework of educational urbanism. With a specific focus on the spatial distribution of secondary schools in the city of Lisbon, it investigates the relationships between the evolution of the city’s urban layout and the functional transformations that occurred along the 20th century. The purpose is to understand how far these schools are incorporated into the urban grid and to explore their potential to perform as a neighbourhood-based institution.

A syntactical-morphological history of Lisbon provides the basis for interpreting the urban evolution of the city along the 20th century and to capture the relationships with its functional structure. As Hillier (1996) suggests, spatial configuration plays a key role in connecting physical form with functions, in that space is an intrinsic feature of urban dynamics. The urban network became the favoured instrument for organizing the urban layout, with a double function: to support the settlement of basic services including mobility and facilities, such as schools, and to organize and control the built environment. Topological properties of the urban network are explored on a global and local scale, such as integration and choice variables.

The paper is organized in two parts. It starts by outlining the evolution of secondary school provision and location in Lisbon with reference to the Western countries context and its main trends. Particular attention is given to the rationale behind both the urban and educational planning and theories, which have run parallel with the construction of school buildings and the conditions that facilitated the development of the city’s school provision and location. The second part focuses on syntactical-morphological features by exploring the spatial distribution patterns of school buildings at both global and local scales. A macro level analysis is followed to understand the relationship between the distribution of secondary schools and the architecture of the urban network. Integration patterns of both global and local scales are numerically and visually compared with the distribution pattern of school buildings at the correspondent periods. Synergy and intelligibility parameters in the scoped timespan are sequentially compared.
It is concluded that the present urban condition of secondary schools shows the juxtaposition of global and local factors, i.e. the presence of a strong relationship with the city's local and global parts.

KEYWORDS

School-place, city-based institution, neighbourhood-based institution

1. INTRODUCTION

This paper is part of a wider on-going research project – “Atlas of School Architecture in Portugal: Education, Heritage and Challenges” - which intends to contribute with new and comprehensive knowledge about school buildings in Portugal for secondary and middle education. It adopts a dialectic relationship between education, urban planning and architecture disciplines. Educational visions, together with emerging concepts in urban planning and architecture theories and practices at the time school buildings were built, outline the research framework. This approach is consistent with a growing body of research showing the potential of school architecture not only to enhance education but also to catalyse urban development while benefiting their social and economical milieu (OECD, 2011, 2014). Educators, urban planners and architects agree: schools are day-to-day facilities and their location, spatial design, physical conditions and resources are important determinants of educational achievement and urban quality of life. Moreover, as urban entities, schools have significant impacts on urban dynamics including mobility patterns, residential choices and real estate development.

This paper focuses specifically on the spatial distribution of secondary schools (regular and technical schools) in the city of Lisbon. The purpose is to understand the associations between the structure of the urban network and the spatial distribution of these schools, both at the global and at the local scales, potentially enabling them to perform also as neighborhood-based institutions thus intertwining learning with live, work and play.

The theoretical premise is that ‘school-place’, defined as the condition that gives meaning to the educational experience, is correlated to the degree to which the school is embedded in its urban context. This includes special features of the school’s physical environment related to the urban built fabric and to the community and also special social, cultural and educational influences. Detailed consideration of school buildings of any period tends to reveal this underlying complexity (Woolner et al., 2005).

It is argued that while schools are important carriers of meanings and values, they help to create and reinforce individual and community identity, as they serve as centres of learning and they connect neighbours with one another. Whereas this function can to some degree be influenced by the design of the school building and its relationship to the surrounding area, the more a school is embedded into the urban context, the greater will be its potential to support a variety of school and community related activities.

The study is organized in two parts. It starts with a review of the secondary school building construction in Lisbon from a historical perspective, pursuing an extensive survey on educational and municipal archives and inventories. It draws on a range of technical data, records and publications on the topic. The mission and the role of secondary schools have played in various periods have also been investigated as a source of historical and social evidences for the spatial analysis through existing literature and photograph collections. Particular attention was given to the rationale behind the educational and urban planning theories, which have run parallel with the construction of school buildings and the conditions that facilitated the development of the city’s school mapping.

The second part explores the spatial distribution of secondary school buildings in Lisbon based on a detailed spatial analysis drawing on longitudinal syntactic data at both global and local scales. A number of studies on urban evolution carried out with the primary intention of understanding the contemporary built environment can be found in Space Syntax literature (Griffiths, 2012),
whether comparing the evolution of spatial patterns at different times or investigating relationships between changing functional pattern and its spatial structure in the urban transformation process. The present study encompasses the theoretical and methodological framework applied in spatial-locational studies. It has involved the ‘cartographic redrawing’ of each period and the combined use of axial and segment angular analysis.

2. A BRIEF REVIEW OF THE SCHOOL BUILDING CONSTRUCTION PROCESS

The first public programme of secondary school building construction in Lisbon goes back to the end of the 19th century. At the time, in most European cities school buildings, in particular those for secondary education, were used as tacit structural elements to shape new expansion areas developed according to ‘regularists’ guidelines (Choay, 1969: 15-26) as illustrated by the French model of lycées. They composed the design and promoted the legibility of the main streets, contributing to the settlement of new inhabitants with important social and economical benefits for the specific areas where they were placed. The hygienic concerns of the time, which had a major influence in urban planning theories, placed emphasis on comfort and health, and consequently in the selection of the location of school buildings within the urban fabric (Frago, 1993-94:29).

Comparing with other European experiences and in particular with the French one, which was of paramount importance in Portugal at the time, Lisbon was a singular case. The urban principles applied in the reconstruction of the city centre, after the 1755 earthquake, restricted the inclusion of this new type of educational facilities as created in the 19th century. Thus, the first two purpose-built secondary schools – a regular school, the so called lyceum, and a technical school - were planned to be located in the Western periphery of the city core: the former in the interior of a large block within the 16th century compact urban fabric, on the West side of the downtown area, and the latter near the harbour industrial sector in a new developed residential area for working-classes families.

Throughout the 20th century, the urban locations of the new schools followed different criteria, according to different urban and educational theories, as well as changing demographics and evolution in the enrolment of school-age population.

In the first two decades of the 20th century, several arteries were efficiently planned and built that intended to be the structural support for the entire Northern urban expansion of the city. Two new lycées and one technical school were built to serve as co-educational schools. The demands of health and hygienic theories required schools to be located in vacant lots within the limits of the new urban expansion area. Similar to the French experience, they occupied large plots near the main avenues, as a prominent-singular entity, a city landmark expressing the image of monumentality that would signal an institution of modern urban life. They took advantage of the plot main frontage to reflect their civic character and foster their presence within the urban fabric. Their configuration varied according to their location within the block in order to solve problems of light and air as required by the hygienic theories, as well as to offer external space for physical activities as claimed by the new educational premises.

Along the next three decades more four single-sex lycées and ten technical schools were built encompassing the urban evolution both to the North and to the West of the city limits. These schools were built as part of state-funded public secondary school construction programs. According to the programs rationale, schools were placed close to main axis in reference places in new or existing residential areas, thus assuming a prominent position and imposing their presence by dominating their surroundings as landmark buildings.

At the time, the emergent process of democratization of education taking place in most Western countries, led modern theories of urban planning to recognize the school building as a place-based institution, a day-to-day facility in close relationship with the neighbourhood. From the Ebenezer Howard’s idea of “social cites” to the principles set out by Unwin, as well as by Perry in the 1920’s or in the German and Dutch experiences of the late 1920’s and 30’s, school premises became a key element of the neighbourhood structure, having an important role in
the settlement of inhabitants. The loss of the monumentally through the reduction of building scale together with the opening of school spaces to the community and the improvement of pedestrian accessibility led to a close relationship between the school and local inhabitants and to the strengthening of social links.

The process of democratization of education in Portugal did not follow the trend observed in other European countries, but the new urban expansion areas promoted by the Lisbon city council along the 1940’s and 50’s, were deeply influenced by these experiences. They correspond to the first large-scale urban operation planned to expand Lisbon by public initiative in order to respond to the lack of affordable housing and to decentralize services and activities to the periphery of downtown, i.e. the traditional city core. Their planning was based on the concept of neighbourhood unit. Implicit in this new model was the vision of a compact, multifunctional and socially diversified city with urban environments that were more attractive and vibrant, capable of promoting a closer community with a greater sense of neighbourliness. More three secondary single-sex schools were built at this time. A female lycée and a technical male school were located in the centre of the new neighbourhood while the male lycée was placed around the edge of the neighbourhood, serving two or more neighbouring groups of dwellings that were within in walking distance. In accordance with the modern thinking, school building design was focused on less formal plan organizations and massing arrangements, looking for a deinstitutionalized character.

The period immediately following the Second World War was one of wide-sweeping social and economic reforms and innovations in the urban and educational fields. It was marked by a shift in planning theory away from a localized design focus and project orientation toward a concern with large scale, multi-community and multi-faceted problems (Lleweldyn-Davies 1972: 104). The right to education and its democratization in most of the European countries was the first condition for the school construction program to become an integral part of urban planning decision-making (Roth 1957:11). The rise in school-age population and the demand for school facilities created intense competition for land and other resources, especially with other community needs, such as affordable housing, parks, and community centres.

Late in the 1950’s and throughout the next two decades, another large-scale planning operation promoted by the Lisbon city council was initiated, corresponding approximately to 1/10 of the total area of the city. The experiments that were being made at that time in the development of new towns in various European countries represented an additional motivation for Portuguese planners. It was not a question of breaking away from the functional principles of housing, work, recreation and circulation, from the Athens Charter, but rather amplifying them and adapting them to new situations with more elaborate proposals. The adopted strategies had made it possible to ensure an effective link between the housing units and their immediate services and educational infrastructures. Outside these planned areas, new developments were promoted by public initiative on a speculative basis. Along this period two more lycées and three technical schools were built. By the end of the 1960’s the growth of secondary schooling challenged the ideological tenets of single-sex schooling and gender segregation was abolished from public schools. Early in the 1970’s a new education act altered the structure and organization of secondary education and regular and technical education were merged since 1976, being offered in the same school.

The increasing demand for school places during the decades of 1970’s and 80’s as a result of the country’s democratization process and new educational policies, implied a transition to singular design solutions for widespread implementation, which has strongly impacted on the appearance of schools as well as on the aesthetic character of the area where such schools are placed. The exigencies of school finance together with larger site area requirements often resulted in school location and design decisions that were aligned with neither educational needs nor urban development needs, but instead were driven by land costs. Moreover, the rejection of urban planning models based on defined catchment areas, in favour of widely overlapping areas of service, led to the construction of new schools in outlying areas. This period is marked by the construction of a set of six secondary schools.
Since the 1980’s the city started losing population to its metropolitan area. The total number of residents at the end of the 20th century was approximately 550,000 inhabitants, similar to that of 1930. From the early 1990’s, the existent secondary school buildings became a focus within the agenda of policies for urban and social revitalization. Secondary school facilities are now being re-examined so as to maximize their public use and to support greater opportunities for community interaction. An effort is being made to transform schools into hubs for community activities, where people of all ages can access education, community services, recreation and culture. This approach has particular interest in the context of an ageing population and declining school enrolments.

3. DEPICTING THE ARCHITECTURE OF THE URBAN NETWORK

Previous studies on the Lisbon syntactic morphological evolution (Kruger; Heitor and Tostões, 1996; Heitor and Pinelo, 2014) have shown how Lisbon’s topological centrality evolved after the 18th century earthquake from a regular grid pattern to a more linear structure and deformed grid. This occurred in the last quarter of the 19th century and was due to the opening of two large avenues perpendicular to the river, following the city’s two main valleys, thus reinforcing the expansion of the urban fabric towards the Northern periphery in detriment to the East-West borders. Following the strategic character of political and administrative interventions over the organization of the city as a means of controlling urban life, these avenues had a role both as a landmark in the Lisbon urban transformation process and a support for the new city expansions developed along the 20th century. This included the opening of several arteries and the construction of modern infrastructures, housing and other facilities promoted by real estate developers and private builders as well as large-scale public operations, carried out from the 1940’s up to 70’s.

A macro level analysis was carried out to understand the relationship between the distribution of secondary schools and the structure of the urban spatial network. Six historical cartographic maps of Lisbon published respectively in 1855, 1911, 1948, 1970, 1997 and 2005, are decomposed into axial and segment maps thus allowing a spatial-temporal analysis of the evolution of the urban network with a time interval of 150 years.

Space Syntax Toolkit (Gil 2015) a front end to Depthmap (Turner 2004) is used to calculate integration and choice patterns at local (radius 5) and global (radius n) scales and to obtain a general picture of the spatial centrality condition. Global and local intelligibility and synergy analyses were also produced to give a further trace of the morphological changes occurred.

Global analysis is used to represent the degree of convergence and dispersion of axial lines and other types of space in the whole system, while local analysis is applied to grasp local grid structures, which can be indicative for the “living centre” at the neighbourhood scale. The objective is to identify the dominant foreground network, marked by linear continuity and the background network with less linear continuity (Hillier, 2009: 8). The understanding of the dual structure of the city provides a more clear impression of the school location.

Then, integration patterns of both global and local scales are visually compared with the distribution pattern of school buildings at the corresponding period. This allows detecting if the (top-down) centralized school planning and location process was sensitive to the actual centrality structure of the network.

Scatter plots showing intelligibility and synergy at the six different periods are sequentially compared. Functional changes are revealed from a syntactical-morphological perspective by highlighting the distribution of schools.
Figure 1 - Axial Integration - Local Integration from 1855 until 2005 a) 1855; b) 1911; c) 1948; d) 1970; e) 1997; f) 2005. All the six axial maps are displayed at the same scale and each dot corresponds to the location of a school.
A visual inspection of both maps (Figure 1 and Figure 2) seems to reveal that the strategic centrality of the urban network dates back to the end of the 19th century, due to deeper hinterland penetration of the South-North axis. Ever since, the geographical expansion of the integration core around these two structuring axes is further emphasized, pushing the “new” integration core towards the North, as observed in the 1911 map and further consolidated in the following periods (1948 and 1970 maps). The integration core has grown to spread out along the main axis, with strong links to the outside. Also it has developed as to become more compact and shaping an emergent deformed grid.

The densification of the deformed grid entails the construction of new residential areas and is accompanied by the extension of the grid towards the Northern and Northeast periphery of the city. The expansion of the urban fabric to the West maintains a peripheral character, also translated by low values of integration, not creating distinct impacts on the spatial configuration at that time. This densification process also reduces the segregation of the peripheral areas, while increasing the levels of integration in the central core, as it is reflected in the 1997 and 2005 maps. Although marginally, the integration core increases and solidifies its structure, shifting slightly to North and substantially reducing the centrality of downtown area. However, this central core is somehow dissociated from the rest of the city, due to the absence of continuity axes supported by local structures, which could join the city as an articulated continuum. The pressure of private investors influenced urban expansion, in particular those scattered developments built between the 50’s and the 80’s, which were developed without the strict control of the city council over the organization of the city.

In 2010, the expansion of the city to the Northeast, following the renewal of part of the riverbank, has an insignificant contribution to the spatial structure of the city as a whole. It does not entail any displacement or growth of the centre as already established since 1948. Despite the new development areas, to a large extent Lisbon’s basic spatial structure has remained the same. It seems that from the last quarter of the 19th century onwards, the city has evolved into a unique collage of various urban grids. This confirms the strategic character assumed by the planned interventions of the late of the 19th century. Besides representing the icons of urban life at the time, i.e. the modernization blueprint, they were also efficient instruments for organizing the urban layout and controlling the city expansion since then.

4. RESULTS

Table 1 provides a synthesis of the axial analysis of this historical process. The analysis includes global (radius n) and local (radius 5) integration, connectivity, intelligibility and synergy at the different evolving stages. It also characterizes the structuring traces of the system, providing a syntactical evaluation of its 150 years timespan evolution.

<table>
<thead>
<tr>
<th>Date</th>
<th>Number of lines</th>
<th>Line length</th>
<th>Global integration (radius n)</th>
<th>Local Integration (radius 5)</th>
<th>Connectivity</th>
<th>Intelligibility factor r²</th>
<th>Synergy factor r²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1855</td>
<td>1449</td>
<td>117,695</td>
<td>0.625</td>
<td>1.434</td>
<td>3.573</td>
<td>0.150</td>
<td>0.345</td>
</tr>
<tr>
<td>1911</td>
<td>2226</td>
<td>163,112</td>
<td>0.692</td>
<td>1.545</td>
<td>3.846</td>
<td>0.127</td>
<td>0.356</td>
</tr>
<tr>
<td>1948</td>
<td>3459</td>
<td>187,610</td>
<td>0.619</td>
<td>1.523</td>
<td>3.802</td>
<td>0.108</td>
<td>0.309</td>
</tr>
<tr>
<td>1970</td>
<td>7846</td>
<td>170,160</td>
<td>0.616</td>
<td>1.476</td>
<td>3.561</td>
<td>0.084</td>
<td>0.293</td>
</tr>
<tr>
<td>1997</td>
<td>7600</td>
<td>176,951</td>
<td>0.652</td>
<td>1.498</td>
<td>3.626</td>
<td>0.088</td>
<td>0.306</td>
</tr>
<tr>
<td>2005</td>
<td>7813</td>
<td>178,698</td>
<td>0.656</td>
<td>1.504</td>
<td>3.634</td>
<td>0.084</td>
<td>0.295</td>
</tr>
</tbody>
</table>

Table 1 - Lisbon metric and axial parameters
The 1855 axial system comprises 1449 lines with an average length of 117m and a global integration of 0.62. By 1948 the system has practically doubled in size (3459 lines) to further doubled again by 2005 (7813 lines). Also an increase in all integration values along the 150 years timespan evolution was observed.

The connectivity value, peaked somewhere by 1948, decreasing smoothly afterwards by 2005, showing that the overall structure of the city has become shallower while the street layout has become better connected. This is mainly due to the combination of areas better served by high through-movement streets linking the core to the edges, made up of orthogonal grids with a continuous and less fragmented urban fabric. An ascending trend for the global integration of the urban layout from 1948 to 2005 is observed, together with a clear demarcation of the integration core. Since the 1948 map, the key integrators are shaped rather like the rims of a deformed wheel pattern. However due to the city topography, the long radials linking to those rims do not fully converge inward at a focal point to create a strong internal hub. The global...
Integration core has shifted first towards the North, then marginally floated to West and East sides and further towards the Northeast. This pattern of expansion and relocation corresponds to "the paradox of centrality" as described by Hillier (1996). The possibility of forming certain edge- to- centerlines effect is minimized by the presence of natural barriers. Besides the increasing size and the diversity of the new urban grids, there is a general evolving trend for both the mean local integration and connectivity values.

Nevertheless a decrease is also detected in the synergy values of the whole urban network, suggesting a loss of synchronization between the local street structure and the wider urban context, i.e. a drop on the symbiotic relation between the local and global structures.

The axial analysis was complemented by the segment analysis so as to identify both the foreground and background networks at each analysis period (Hillier, 2009: 8). Grasping this duality allows a deeper understanding of the school location and relative position within the city. The analysis (Figure 3) confirms the previous findings, which have shown that the foreground network gains its high centrality at the cost of creating a segregated background, and reinforces the potential of the foreground network to structure the urban network by creating rings that help integrate the background.

Table 2 summarizes the axial analysis, featuring both global and local integration, as well as global and local choice values. All values are qualitatively displayed according to the featured quartile. Also, schools are characterized according to their type, i.e. Lyceum, Technical School, Industrial Institute, 2nd cycle school or Secondary School, original gender and type of building i.e. provisory or specifically built for purpose.

School #1 is the only present in the 1855 map (although in its provisory building) and its global integration value is slightly above Q3, placing it in the integration core. In the 1911 map four lyceums were located in the most integrated areas within the system as part of the integration core while two technical schools (#5, #6) occupied less integrated sites, i.e. either the 1st or 2nd quartile.

By 1948, another three schools were built, totaling nine schools: seven lyceums and two technical schools (#5, #6). Global integration values range from the 1st to the 4th quartile, and both provisory lyceum buildings (#8, #9) and a technical school (#6) feature low integration values (1st and 2nd quartile). All the lyceums show high local integration values, but the technical schools feature either in the 1st or 2nd quartile. Moreover seven schools are located within the integration core of local choice and the remaining (#1 and #5) is in the 3rd quartile. Conversely global choice values are slightly lower, ranging from the 2nd quartile (#2) to the Integration core (#3, #4, #8, #9). Also, it is observed that school #2 has global choice values represented in the 2nd quartile, while the global integration is in the 4th quartile. Conversely, school #9 is in the integration core regarding global choice values while its global integration is in the 1st quartile.

Along the next two decades (1970 map), another 20 new schools were built. The majority are located within the global integration core, which, as previously referred, has moved North to embrace the new commercial and business areas. Schools (#6, #8, #15, #19, #20), which are located in the Western part of the city, feature the lowest global integration values. At this time 21 of the total of 29 existing schools are located within the local integration core, assuming a prominent local position. Choice values, both at global and local scale feature high outcomes, mostly in the integration core.

Between 1970 and 1997 more seven school were built. The global integration analysis features fifteen schools located within the integration core and four schools in the least integrated quartile. A total of twelve schools (located in South-Western and Eastern part of the city) are in 1st and 2nd quartile; however, most of these schools feature high local integration values. Technical schools #20 and #24 both have the least integrated global integration values and the highest local integration values.

In terms of global and local choice values, schools show a consistent pattern showing high values.
Table 2 - Axial Analysis Global Integration (radius n), Local Integration (radius 5), Global Choice (radius n) and Local Choice (radius 5) comparative representation, according to the Quartile (1 to 4) in the 1855, 1911, 1948, 1970, 1997 and 2005 maps for schools #1 to #36. Framed cells represent provisory buildings. Legend: L - Lyceum; TS – Technical School; Inst – Industrial Institute; 2C – 2nd cycle school and ES – Secondary School; M- Male; F- Female; MF – Male and Female.
In 2005 the city of Lisbon comprised a total of 36 schools. The global integration analysis features six schools in the 1st quartile and five schools in the 2nd quartile. Similarly to the 1997 analysis, the least integrated schools are located to the Southwestern and Eastern periphery of the city. The local integration analysis features only six schools in the 1st or 2nd quartile and 24 schools in the integration core. Along the urban development (Figure 6 c) and d)) and consolidation process former female lyceums and technical schools became in the most integrated axis of the system, thus becoming more visible and integrated than the first male lyceums built in the first quarter of the 20th century.

Regarding the choice analysis, local choice values are greater than global choice values. Throughout the six periods under analyses schools are typically located within the background network. This reinforces the concept of background network, and its residential vocation, which also restrains and structures movement through a distinct geometry, thus conferring each background network a new spatiality and feeling (Hillier 2007, 2010). Nevertheless, most schools are located relatively close to the foreground structure, which makes them highly accessible within the city (Hillier 2007, 2010).

In terms of axial synergy, as observed in Table 3, schools (represented with blue dots) tend to lie above the main regression line of synergy and distribute within the top- right zone of these plots, which indicate that they are more integrated than the average level of the whole city. Also it is observed that schools shape a rather linear pattern, which may be interpreted as a kind of hierarchy when treating schools as part of the city school mapping.

In terms of axial intelligibility, as observed in Table 4, schools (represented with blue dots) tend to lie above the main regression line. But to the exception of some outliers, the distribution is typically in the lower zone of these plots.

Figure 3 - Axial Synergy along the 150 years timespan. x-Axis: Axial global integration; y-Axis: Axial local integration. This graphic is a simplification of a scatterplot: each area represents the density of occurrences (from 33% to 100%).
Furthermore, a 150-timespan synergy and intelligibility analysis was drawn in Figure 4. The regression lines have minor divergences and schools are cohesively distributed throughout the timespan.

Figure 4 - Axial Intelligibility. x-Axis: Axial global integration; y-Axis: Axial Connectivity. Legend: This graphic is a simplification of a scatterplot: each area represents the density of occurrences (from 33 to 100%).

Figure 5 - Axial Synergy and Intelligibility comparison
Figure 6 characterizes the axial integration according to the typology of the school (Lyceum; Technical School; Industrial Institute; 2nd cycle school or Secondary School). In the late 19th and early 20th century the focus was given to the construction of male schools. With urban growth and the democratization of education (from 1912 to 1970: Figure 6 c) and d)) a significant number of new female lyceums and technical schools were built. Later on, theses schools become more integrated in the global system and than the first wave of lyceums (Figure 6 a) and b)).
5. CONCLUSIONS

The analysis shows that throughout the period under consideration ‘school-place’ in Lisbon has evolved from a prominent-singular entity, a city landmark portraying the image of monumentality, to a more neutral-commonplace entity. This loss of monumentality led to the reduction of the building scale enabling it to operate as a neighbourhood-based institution. This shift occurred from 1940’s onwards in line with the state-funded programs rationale, when school buildings were placed in prominent places within new or existing residential areas.

The present urban condition of secondary schools is supported on the juxtaposition of global and local factors, i.e. the presence of a good relationship between its local and global parts. Many schools feature a favourable location regarding its global and local axial integration values. This is a reflection of a careful school planning process (based on top-down decisions) in that schools usually have both a strategic position at the city-wide scale and a compact and inter-accessible local structure. Moreover the shift of monumental to local, transformed the perception of the school building, while revealing a joint strategy towards a new significance of education, which combines modern educational, urban planning and architectural theories and practices. This trend acknowledges the important role of the school as a shared public resource and gives meaning to school-place.

Finally, it is important to mention the limitations of this study. When examining the average integration value each school holds both at the global and local level in the six axial maps some variances in their functional aspect are revealed from a spatial perspective. Hence, a more detailed analysis focused on the best and least-served school locations is needed. In particular the relationship established between the local spatial characteristics of these schools and their potential to perform as shared public resources and neighbourhood base institutions should be questioned. Connections that can be made between learning, living, working and leisure remain to answer. Up till now, since the work of both Perry (1929) and Stein (1928) on planning for the neighbourhood unit, insufficiently empirical data exists on sitting new school facilities within the context of an all-integrated and responsive city.

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# QUANTITATIVE COMPARISON OF CITIES:
Distribution of street and building types based on density and centrality measures

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ABSTRACT
It has been argued that different urban configurations - planned vs. organic, treelike vs. grid like - perform differently when it comes to the intensity and distribution of pedestrian flows, built density and land uses. However, definitions of urban configurations are often rather abstract, ill-defined and at worse end in fixed stereotypes hiding underlying spatial complexity. Recent publications define morphological typologies based on quantitative variables (e.g. Barthelemy,
QUANTITATIVE COMPARISON OF CITIES:
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1. INTRODUCTION

1.1 GENERAL BACKGROUND AND AIM

The world is currently facing an unprecedented global urbanization, where there will be three billion more people living in cities within the next 25 years. This will set the frame for the future development of our societies and presents unprecedented expectations on the future governance, planning and design of cities and on urban morphology as an essential knowledge base for urban design. In response to this, the objective of an international project under the name SMoL,1 is to develop and test consistent and sound methodologies and techniques for measuring and comparing central variables of spatial urban form, focusing on the main elements; the street, the plot and the building (Whitehand, 2001; Kropf, 2011) as well as the interplay between them (Marcus et al., 2017). Describing and understanding how these spatial elements influence movement in cities, as the central driver of urban dynamics, will help us better grasp how such flows in turn underpin and structure broader urban processes of a social, economic and environmental kind.

Despite the long tradition of studies in urban morphology, spatial analysis and urban modelling, there is still need to better identify how such research may inform the practice of urban planning and design and from that, build a more consistent theoretical and methodological framework for research, with direct bearings for the professions. We see the direction of typo-morphology as a way forward, as they allow for the definition of types based on multiple variables in a precise

1 Spatial Morphology Lab (SMoL) is a three year project financed by Chalmers foundation, led by Lars Marcus and Meta Berghauser Pont.
and repeatable manner, enabling the study of large samples and the comparison between both cities and regions. What we aim for is to include streets, buildings and plots and the related measures of distance, density and diversity in a taxonomy of cities, where elements in the same group (i.e. cluster, type) are more similar to each other than to those in other groups. This enables us to not only describe traditional urban form as found in historical cores and their immediate vicinities, or what Serra (2013a) calls the city with ‘good form’, but also the city ‘without form’, containing late 20th century and contemporary urbanization. This, in turn, enables urban design practitioners to frame design choices in terms of such multi-variable types instead of current, often ill-defined types, at worst stereotypes, hiding underlying spatial complexity (ibid.).

This paper explores street types, following the work of Serra (2013a), with the purpose to, firstly, gain a better understanding of how street types are composed and distributed not only within a city as in Serra (ibid), but also across different cities. Four cities are included in this comparative research: London, Amsterdam, Stockholm and Gothenburg. Secondly, we explore how these street types relate to the distribution of density types, building further on the work of Berghauser Pont and Haupt (2010).

1.2 TYPOLOGIES

Typologies play a role in urban studies since a long time. The classic studies of urban morphology (e.g. Caniggia and Maffei, 2001; Conzen, 1960, Whitehand, 2001; Panerai et al., 1977, Panerai et al., 1999) described either types of singular urban elements with a rather high detail (e.g. types of streets, urban blocks, parcels, buildings) or aimed for a description of complete systems. Traditional typologies focussing on separate elements allow for the understanding of differences of one spatial feature, but lack the interrelation between the elements and between scales. The understanding of the whole system on the other hand requires a reduction of the urban environments to the main elements of the whole urban system on the larger scale and therefore lacks precision.

Further, classic studies focused mainly on qualitative methods, where in recent years this has shifted towards more quantitative methods. Martin and March described already in 1972 the necessity to quantify in order to achieve a higher precision in the understanding of urban form in their seminal book “Urban Space and Structures”. They elaborated that a quantitative approach towards urban form and structure became relevant with the aim for understanding entire spatial systems and specifically the relation between its elements or as Steadman described it: “understanding relationships and setting out ranges of choice.” (Steadman, 2016, p. 296). They explained further that quantification is an important step towards a comparative assessment of urban environments, which represents one of the main purposes of a typology.

Only recently, studies of urban morphology have (again) been aiming for classifications or typologies based on quantitative description of spatial elements. Berghauser Pont and Haupt (2010) developed a multi-variable approach towards built density and Barthelemy (2015) identifies classes of street patterns applying a multi-variable approach, using urban block shape and area. Although Berghauser Pont and Haupt as well as Barthelemy elaborate their typologies in a multi-variable approach, they focus in their description on features each belonging to a specific scale. The research of Serra (2013a; 2013b; Serra et al., 2016) on the other hand, approaches the understanding of the metropolitan structure in a multi-variable, but also multi-scalar way. Gil et al. (2012) use similar methods with the aim to compare two neighbourhoods in a multi-variable and multi-scalar approach. The integration of street and urban block typologies with different detail is leading to a more precise description of the neighbourhoods. In this paper we will draw from these experiences and compare whole cities.

We should here make a distinction between typology and taxonomy. The former is primarily conceptual, the latter empirical (Bailey, 1994) using statistical analysis to find similarities in the data (cluster analysis). We will combine the two following what Bailey (1990) called “the operational or indicator level”. For the sake of simplicity we will, however, use typology in the paper where one also could read taxonomy.

A fifth city in Sweden will be added to be able to compare three Swedish cities with similar growth patterns but of different size, besides the comparison of three main cities in Europe.
Gil et al. (2012) as well as Hausleitner and Berghauser Pont (2017) use similar methods with the aim to compare neighbourhoods respective whole urban systems in a multi-variable and multi-scalar approach.

1.3 STUDY AREA

Three main cities in Europe are selected for comparison in this study because they, on one hand, carry certain socio-economic and historical similarities, while on the other hand, vary in their regional structure; Stockholm as the planned finger-city where green and blue wedges cut deep into the city centre, London as the organic growing concentric conurbation and Amsterdam as part of the poly-central conurbation Randstad. A fourth city was added, that is Gothenburg, to see whether another Swedish city will show more similarities with its ‘bigger brother’ Stockholm than with the other two European cities. The study areas aim to include the whole urbanized part of the cities or, in other words, their metropolitan areas, which span out of their mere municipal borders. For this reason, we used the Urban Morphological Zone (UMZ) boundaries, as they are defined by the European Environment Agency (EEA) and the Eurostat for all European cities.4

However, because of the highly irregular boundaries of the UMZs which could become problematic to the syntactical analysis of the networks, what was instead used as the boundary of each study area, was the convex hull of each UMZ. Finally, to address the possible ‘boundary effect’ to the calculation results, the area which was analysed was at least 25km larger than the study area in all directions.

2. METHOD

The central methods used in this paper can be divided into methods for editing the main datasets to arrive at the network and density model, spatial analysis and statistical analysis which will be discussed in the sections below. The sequence of the methods and how they relate to one each is explained in Table 1 below.

<table>
<thead>
<tr>
<th>Task</th>
<th>Data Sources</th>
<th>Steps</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Street network types</td>
<td>Road centre line</td>
<td>1. Edit map</td>
<td>Remove errors, duplicates, isolated lines</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Snap endpoints</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2. Spatial analysis</td>
<td>Angular betweenness centrality (radius 500 – 30000m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3. Statistical analysis</td>
<td>PCA analysis</td>
</tr>
<tr>
<td>2. Built density types</td>
<td>Laser data</td>
<td>1. Edit map</td>
<td>Create Digital Height Model (DHM)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Calculate average building height</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Correct errors</td>
</tr>
</tbody>
</table>

4 Urban morphological zones (UMZ) are defined by Corine land cover classes considered to contribute to the urban tissue and function. A UMZ can be defined as “a set of urban areas laying less than 200m apart” (source: http://www.eea.europa.eu/data-and-maps/data/urban-morphological-zones-2006 (download date 13-7-2016)
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2. Spatial analysis

2.1 NETWORK MODEL

The street network models are based on the national road database of each country; the NVDB (Nationell Vägdatabas) for Sweden, the NWB ( Nationaal Wegenbestand) for the Netherlands and the OS MasterMap ITN (Integrated Transport Network) for the UK.\(^5\) In all cases the source maps show sufficient detail and coverage of the road network, but also the same basic representational principles. All roads are represented with one line irrespectively of the number of lanes, except from Motorways and Highways which are represented with two lines, one for each direction, again irrespectively of the number of lanes.

We processed the original Road-Centre-line maps with two objectives; first to create line segment maps on which we could apply Angular Segment Analysis and second to create comparable representations of the street network, both in the types of roads included and in the level of detail. For the purposes of this analysis we used the motorized network of each area.

The processing of the original Road-Centre-line maps involved sorting and editing procedures, where the same rules were applied to all cities. First, we sorted out roads where cars are not allowed access (e.g. pedestrian streets, alleys, paths, bicycle lanes); second , we followed the same editing and generalizing procedure for all maps aiming to remove errors, but most importantly to optimize representation and reduce calculation time by reducing the number of line-segments and finally, to increase comparability between networks. This process, before the final segmentation of the Road-Centre-lines to line-segments, included removing duplicate and isolated lines, snapping and generalizing.\(^6\)

To obtain a detailed multi-scale centrality description of the four metropolitan regions we carried out network centrality analysis of the street network models, calculating angular betweenness centrality (i.e. choice) with different metric radii, from 500m to 30km. To provide a uniform and continuous sampling of centrality the radius are equally spaced and have a small interval (i.e. 500m) in smaller distances up to 10km, where one observes greater variation in centrality values, and a larger interval (i.e. 5km) above 10km up to 30km. This results in a series of 24 radii per street segment.\(^7\)

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\(^5\) The Road-Centre-line maps used, come from the official road authorities; Trafikverket for Sweden, Ordnance Survey for the UK and Rijkswaterstaat-CIV for the Netherlands. The downloads were done from May to October of 2016. The NVDB is open access and was downloaded from the Trafikverket website (https://lastkajen.trafikverket.se, date of download 15-5-2016, last update 8-11-2015). The NWB is also open access and was downloaded from the Rijkswaterstaat website (http://www.rijkswaterstaat.nl/apps/geoservices/geodata/dmc/nwb-wegen/geogegevens/shapefile/Nederland_totaal/, download date 12-10-2016, last update 6-12-2016. The ITN was delivered upon request from the Ordnance Survey (https://www.ordnancesurvey.co.uk, download date 29-11-2016, last update 3-10-2016).

\(^6\) The snapping threshold used was 2m (end points closer than 2m were snapped together). The generalizing threshold used was 2m (successive line segments with angular deviation less that 1m were merged into one).

\(^7\) The software used for processing the original Road-Centre-line maps were FME Desktop 2016, Mapinfo Pro 15.0 and PST (Place Syntax Tool , plugin for Mapinfo Pro 15.0). The software used for analysing the processed line-segment maps was PST.
2.2 DENSITY MODEL

The density model is based on laser dataset 8, including coordination and elevation values for each point collected from LiDAR (Light Detection and Ranging). A Digital elevation model (DEM) and Digital surface model (DSM) was extracted from the laser dataset with an average resolution of 2m. Then, DEM was subtracted from DSM to make a new surface model called Digital height model (DHM) which contains the real height values of the features on the ground. Finally, building footprints were added and the average height value of the area covered by each footprint was considered as the height of each building.9 Buildings with no or incorrect heights (too high, too low, zero or negative values) were corrected using Google street view or similar online services. In cases where it was impossible to find the building height using above-mentioned methods, we used a buffer around each building separately and considered the average height value of the surrounding buildings as the height of the building(s) in question.10

To obtain a density description of the four metropolitan regions we carried out an accessible density analysis using two variables: Floor Space Index (FSI) and Ground Space Index (GSI). The radius used is 500m which has proven to be the most accurate distance to capture building types as is discussed extensively in Berghauser Pont and Marcus (2014). Firstly, the average height of the buildings derived from the height model was multiplied with the built up area to calculate the built volume to then divide by 3m to arrive at an estimation of gross floor area (GFA). Secondly, the denominator B of the simple fraction of density A/B is arrived at by calculating the area of the convex hull using the end points of the street segments that are reached through the network within a radius of 500m using PST. The numerator A is the total GFA, respectively total built up area, within the same radius of 500m.

2.3 STATISTICAL ANALYSIS OF STREET CENTRALITY

To be able to describe and compare the metropolitan regions based on multi-dimensional centrality results, we perform two main statistical analyses in R software: Principal Component Analysis (PCA) as a means of dimensionality reduction and of extracting the most representative centrality scales of each region; and k-medoids clustering to classify the street segments based on their individual centrality profile, obtaining a centrality typology of streets.

For the statistical analysis of the results we only consider the segments contained in the study area and ignore all others to avoid using values affected by edge effect. Furthermore, we only consider the values of segments that are part of the main component of the graph, ignoring values of smaller “islands”11. As a first step, all centrality measures are converted to z-scores to be able to compare and combine them irrespective of the value ranges.

Next we run PCA on the betweenness centrality results separately for each city following the method proposed by Serra (2013a; 2013b). With the PCA results we make a scree plot to identify the number of components that explains most of the variation in the data. To choose the number of components to be extracted, one should look for an elbow in the plot’s curve or consider components with an eigenvalue close to 1 or greater. We then rotate the selected number of principal components (using the VARIMAX rotation method), so that the correlation of each component with each of the original variables is either maximized or minimized. This operation makes the existing associations between the principal components and the original variables clearer. After this step one can explore what each rotated component represents in terms of centrality, plotting their loadings (i.e. the correlations between each component and the original variables) in the y-axis and the radius in the x-axis. Each component corresponds to a specific range in the metropolitan centrality continuum of scales. How the components’

8 Lantmäteriet (https://www.lantmateriet.se/)
9 It should be noted that building heights of Amsterdam and London were received in ready-to-use formats: 3dBAG from ESRI (http://www.esri.nl/) and Ordnance Survey (https://www.ordnancesurvey.co.uk/) respectively. Further, it should be noted that for London, the dataset for building height was smaller than the study area based on the UMZ. This will be corrected, but the data was not available for this paper.
10 The buffer distance chosen varied according to the average density of buildings in that area.
11 Islands are small isolated groups of street segments that are not connected to the main street network.
loads of each city differ or, on the contrary, resemble each other, is an interesting object of comparison and discussion on their urban configuration.

These principal components are also an appropriate input to the next step of unsupervised classification with clustering. The orthogonality between components ensures that the variables used for clustering have the lowest possible correlation, which is desirable because co-linearity is known to bias clustering results. We use the k-medoids clustering algorithm (also known as Partitioning Around Medoids, PAM) similar to k-means, which uses a case as the centre of every cluster instead of the cluster mean, making it more robust to the presence of outliers. The k indicates that the algorithm can identify any number of clusters but this number (k) must be defined a priori. For this purpose one has to calculate the algorithm for a range of k values, for example between 2 and 25, and make the scree plot. The identification of an elbow in the plot is again an indication of a suitable number of clusters.

The clustering analysis is performed on the data of the four cities combined using the results of the PCA. From this data we have excluded all the cases where the betweenness value is 0 in every analysis radius, which indicates dead ends and already represents a uniquely identifiable class of paths. Once the cluster solutions are calculated we create a series of boxplots of the centrality profile of every cluster, plotting along the y-axis the cluster’s centrality values and along the x-axis the metric radii. The final stage in defining a typology of street centrality involves the comparison of the centrality profiles of the cluster solutions and choosing one that contains a small set of clearly distinctive profiles.

2.4 STATISTICAL ANALYSIS OF DENSITY

The clustering analysis of the density model is similar to the described method above, but does not need the PCA as only one radius is used (i.e. 500m). Fuzzy c-means clustering is used in Matlab, which allows each data point to belong to two or more clusters with varying degree of membership. This is done on the basis of the distance between each data point and each cluster centre, comparable to the clustering method k-medoids clustering described in the former section. As mentioned, the number of clusters (k) has to be chosen by the user, a priori. In the case of density, we know that each cluster corresponds to a building type described by GSI and FSI following Berghauser Pont and Haupt (2010) and choosing a number of clusters comes down to estimating the number of building types. Further, since we also have an idea about where a specific building type is located on the GSI/FSI graph we can estimate its centre (ibid, p.191). The building type centres are therefore used as set starting points for the clusters. From this data we have excluded all the cases where the GSI value is 0, which indicates areas without buildings and already represents a uniquely identifiable class.

The iteration process then uses the cluster centres to update the membership grades and calculates the sum of the distance between every data point and every cluster centre with the membership grades as weights. The closer a data point is to a centre of a cluster the larger membership grade it is assigned to the cluster. The iteration stops when the change in sum of the distance from one iteration to the next is less than ε or when n iterations has been done, where ε and n are set in advance. The output is the membership grades of all data points to all clusters when the sum of the distance between each data point and each cluster centre is minimized.

3. RESULTS

The street network and buildings models of the four study areas (Amsterdam, Gothenburg, London and Stockholm) have been analysed and the betweenness centrality and density results were processed statistically, following the methods described in the previous section, producing one set of network centrality types (‘paths’) and one set of building density types (‘places’). These results and the relation between the two sets are described next.

12 Due to the size of the data set, we used a faster version of the PAM algorithm, called CLARA (Kaufman and Rousseeuw, 1990), which runs on samples of the entire data set.
3.1 CENTRALITY TYPES

The first step of the statistical analysis (PCA) reduced the 24 radii of betweenness centrality results to three rotated components that meet the two scree plot test conditions, and explain 94% to 97% of the total variance of the original variables. The charts in Figure 1 represent the loadings of the three components and show the radii dominating each one. The components correspond to the natural scales of the four cities’ betweenness centrality structure, namely: the city scale, the *neighbourhood* scale and the *metropolitan* scale. This is in line with the findings of previous work by Serra (2013a; 2013b), albeit then only within the context of a single metropolitan region (Porto’s, Portugal). The dashed line marks the transition between scales and reveals a small difference between cities: in Gothenburg and Stockholm the neighbourhood scale is up to 2500m while in Amsterdam and London it is up to 3000m; in most cities the city scale stops at 10km, except in Amsterdam where it extends up to 12km.

This division of the extended centrality structure of the four cities into just three dominant centrality partitions is, in itself, quite remarkable. It corroborates the findings of (Serra 2013a; 2013b), suggesting that such basic, triple structure of cities, might in fact be general. With hindsight, one could say that the centrality continuum of large urban areas would naturally be divided in this way: into neighbourhood-scaled, city-scaled and regional-scaled structures. However, these results provide solid evidence that this is indeed so, moreover in a rather regular way. They show that, underneath the visible morphologic variability of the four studied cities, their spatial structures (as described by betweenness centrality) are characterized by only three basic centrality regimes and, therefore, by only three basic spatio-functional scopes.

These dominant scales are the variables used to identify the centrality types of the street segments of the four cities, and results in a typology of five ‘path’ types that have different roles and constitute different structures. Four types are the result of the clustering analysis and their profiles are presented in the boxplots of Figure 2. These types include: ‘pulp’ (cluster 1) representing the mass (60 – 70%) of street segments that do not play a significant role in the urban structure at any scale, and correspond what has been previously termed as ‘background network’ in space syntax literature; ‘metropolitan’ (cluster 2) with the segments of increasing betweenness at higher scales; ‘neighbourhood’ (cluster 3) with segments that have a high betweenness at lower scales but become irrelevant at the large scales; and ‘city’ (cluster 4) with segments that have a consistently high betweenness at most scales, but dropping clearly at the most local and regional scales. The fifth type has a betweenness value of zero at all scales, representing the dead ends as a clearly distinct type.

The spatial distribution of these ‘path’ types (Figures 3 and 4) reveals their individual identity and demonstrates their role in the four cities. But it also shows some differences in the way the four cities are structured at these different scales. Amsterdam presents a very homogeneous core...
Figure 2 - Boxplots showing the distribution of betweenness centrality values in each cluster for every radius distance.

structured by a city scale network, similar to London but in this case multiplied several times due to its size; while Gothenburg and Stockholm show an encroachment of the metropolitan scale to their historical cores, which radiates out and the city scale structures hang from and connect these metropolitan branches. Neighbourhood scale structuring paths also appear more concentrated forming grid-like structures in Amsterdam and London, as opposed to the two Swedish cities.
Figure 3 - Maps of the four cities showing the spatial distribution of path types.\textsuperscript{13}
Despite these spatial differences, the overall composition of the four cities in terms of path types is rather similar (Figure 5a and b). The main aspect of note is the pairing of Amsterdam and London on one hand, and Gothenburg and Stockholm on the other hand in having similar path centrality profiles, with the Swedish cities having a smaller share of neighbourhood types, versus a higher share of city and metropolitan types.

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3.2 DENSITY TYPES

The density variables FSI and GSI are used to identify density types and results in a typology of seven ‘places’. Their profiles are presented in the Spacematrix charts of Figure 6 and include: ‘no buildings’ (cluster 0) where density is zero; ‘sprawl’ (cluster 1) with low FSI and GSI; ‘suburban’ (cluster 2); ‘compact low’ (cluster 4) where both FSI and GSI get slightly higher. Then we have three types with higher average building height: ‘city centre’ (cluster 3) with the highest combination of FSI and GSI; ‘compact city’ (cluster 5); and ‘modernistic’ (cluster 6) with a more spacious urban layout.

Figure 6 - Spacematrix charts showing the distribution of FSI and GSI values in each cluster.
Figure 7 - Maps of the four cities showing the spatial distribution of 'place' types.
Figure 8 - Maps of the city centre of the four cities, at the same scale, showing the spatial distribution of ‘place’ types.
3.3 RELATION ‘PATHS’ AND ‘PLACES’

When looking at the relation between centrality and density types, two things are interesting to discuss: first, how the types group and whether certain combinations dominate; secondly, whether this is similar for all four cities.

In figure 9 (a) we can see how places are distributed within each path type. Paths of the metropolitan type, for instance, often come along with places of the sprawl type or with areas with no buildings at all. Figure 9 (b) shows how paths are distributed within each place type, in other words, which paths dominate in which places. The sprawl type, for instance, is combined with all path types in similar frequencies as the suburban type drops when it comes to the metropolitan type. Looking in more detail into the frequencies of the denser places (see figure 9 c), we find that compact city groups most often with the paths at neighbourhood scale, followed by city scale.

When looking at the differences of this grouping in the four cities, we see how Amsterdam and London show similar patterns as well as Stockholm and Gothenburg. The only exception is the path of the metropolitan type where London performs different from the others. This can maybe be explained by the fact that the size of London is so different from the others that what is captured in the metropolitan path in London actually is representing the city scale. We would need to add analysis at higher radii to test this hypothesis.

4. DISCUSSION

We have shown that working with types is a fruitful way to compare whole cities in terms of ‘paths’, defined through the clustering analysis using the betweenness centrality measure through all scales and ‘places’, defined through the clustering analysis using the accessible density measures FSI and GSI at radius 500m. These types are absolute and all-encompassing concepts existing across the different cities that summarise the complexity of various analysis measures and scales.

The proposed combination of PCA and clustering to define paths may seem complex and one needs to question whether only PCA is informative enough on its own. Figure 10 shows how the rotated component RC1 (representing the city scale) shows similarities to the path ‘city’. However, RC1 also covers in a continuous scale all other paths in the network, and ‘city’ paths have high values on more than one scale. This discrete identification of the paths’ profile makes
cluster analysis an important complement to PCA, capturing the overlapping of scales. The streets of the path type ‘city’ have for instance overlap both with the higher and the lower scale. Something similar can be seen when comparing the analysis of a single density variable such as FSI with the places defined through cluster analysis using two density variables (i.e. FSI and GSI). The map showing the places is more informative as it not only informs us which numeric density we have at hand, but also which building type is dominating the area.

Besides the clustering in types, it is worth mentioning how in all four cities, three basic centrality regimes were found and that, underneath the visible morphologic variability, their spatial structures are characterized by only three basic spatio-functional scopes. Further, the main aspect of note is the pairing of Amsterdam and London on one hand, and Gothenburg and Stockholm on the other hand in having similar path and place profiles. The results show a clear relation between denser places and paths of the city and neighbourhood type. On the other hand, paths of the metropolitan type are often found in combination with the least dense places.

A lot of interesting new questions were discussed while working at this paper and studying the results of which we want to mention three.

Firstly, when seeing the interesting grouping of cities, that is, Amsterdam with London and Gothenburg with Stockholm, we are eager to add more cities. One trajectory is to add more Swedish cities of different size, to see whether we can speak of a typical Swedish city with great similarities in the distribution and frequency of both centrality and density. Another trajectory is to add more main cities in Europe to see how many types of city we have in Europe. This can easily be extended even further to other continents.
Secondly, we can add the other core variables of spatial urban form as we discussed in the introduction where the two most important additions we see now are 1) the closeness centrality measure of integration and 2) the patterns of plots that will make the trilogy of the main elements of urban form; the street, the plot and the building, complete.

Thirdly, except for the association between the types as was discussed in this paper, it would be interesting to develop a typology based on the pairing of types using cross tabulation. The same density clusters (places) can hold very different paths and, depending on this grouping, might perform very different in terms of social and economic outcome. Correlating these “combined types” with pedestrian and vehicle flows and economic activities is therefore an extremely interesting next step.
REFERENCES


ABSTRACT
It is well understood that transport mode choice is effected by journey-distance and journey-time (Plaut 2005; Pucher and Dijkstra 2003; Schwanen and Mokhtarian 2005; Wardman, Tight, and Page 2007) We also know that configurational attributes effect the locations of retail and commercial activities (Hillier et al. 1993), and these in-turn influence residential location choices. Finally, specific socio-demographic groups have different preferences regarding their choices of transportation.

The research reported in this paper sought to investigate whether configuration, along with other planning variables, have a role on transportation mode choice. Since the regularity or deformity of urban grid may have an effect on Space Syntax analysis (Ratti 2004a, 2004b, 2005), two gridded and two non-gridded US cities were chosen. For this investigation seven land use variables, ten socio-economic and demographic variables, and three transportation variables in addition to six traditional Space Syntax variables were collected and used.

Data were assembled from online open source databases of the respective cities and the US census bureau. Space Syntax topological and angular analysis of CAD drawn axial lines and street centerlines extracted from GIS maps were performed. ArcGIS spatial analysis tools were applied to combine land use, socio-economic & demographic, transportation and Space Syntax variables to the scale of census block-groups that was selected as the study unit. Several multiple regression and linear regression analyses indicated that renters and non-family households are configurationally separated from homeowners and family households: the former locating themselves in integrated areas where businesses are located. Homeowners and family households prefer segregated areas and tend to drive to work. The results also indicated a definite role of city layouts. One important variation observed in our comparative analysis between gridded and non-gridded cities was that choice was an important indicator for gridded cities while integration was for non-gridded ones. Although the reason for this is speculative at this point, this distinction will serve as an important beginning for future investigations and understanding the particular syntactic properties of gridded American cities.

KEYWORDS
Space Syntax, Gridded Cities, Transportation Mode, GIS, Residential Location
1. INTRODUCTION

Over the past three decades, space syntax theory has provided important computational support for the development of spatial morphological studies to analyze both architecture and urban systems. It has been widely used for modelling pedestrian and vehicular movements (Hillier, Penn, Hanson, Grajewski, & Xu, 1993), crime analysis (Jones & Fanek, 1997; Nubani & Wineman, 2005), traffic pollution control (Penn & Croxford, 1997), and way finding processes (Haq, 2003; Peponis, Zimring, & Kyung, 1990). Space syntax provides a configurational description of an urban structure and attempts to explain human behaviors and social activities. This paper investigates whether space syntax variables have any significant relationship with preferences of residential locations and choices of travel mode. To that end, two pairs of American cities (two gridded and two non-gridded) are selected as case studies. This also provides some indications whether the gridded-ness of urban form has any effect on the strength of relationships that space syntax may have with choices of travel mode and preferences of residential locations. Additionally, a new methodology of considering configuration values, one that considers urban areas instead of linear elements, is introduced.

1.1 OBJECTIVE OF THE STUDY

Configuration of the urban grid is an important generator of aggregate patterns of movement in urban areas (Hillier et al., 1993). Retail and commercial land uses migrate to these configurationally hotspot locations to take advantage of the economic opportunities created by movement (Hillier, 1996). This study realizes that these retail and commercial areas are also work places for a good number of people. Since distance of residential location from work is an important factor affecting the choices of transportation mode, this paper aims to investigate the preferences of homeowners and family households on residential locations as opposed to renters and non-family households in the context of configuration. There is a common understanding that renters being more mobile can revise location decisions more easily than homeowners who might be constrained by a larger set of non-flexible housing options. Hence, the study will examine what relationships might exist between tenure type, household type, and travel mode choice. The other objective of this study is to examine the differences between the syntactic properties of gridded and non-gridded cities in the study of transportation mode choice.

1.2 HOW IS CONFIGURATION RELATED TO LAND USE AND TRANSPORTATION?

A series of papers (Hillier et al., 1993; Hillier, 1996, 1999), now classic, have outlined a generic process by which spatial configurations, through their effect on movement, first shape, and then are shaped by, land-use patterns and densities. Inherently land use pattern follows the hidden property of spatial configuration. Some movement-attractive land uses naturally migrate to more integrated streets (axial lines). The process of attracting uses and multiplying movement has a cyclic nature shaping the land use pattern of urban areas (Hillier, 1996; Thakuriah, Metaxatos, Lin, & Jensen, 2012). Topçu, Topçu, and Deniz (2007) states “The layout of space first generates movement, then movement-seeking land use migrates to movement-rich lines, producing multiplier effects on movement which then attract more retail and other uses, and this leads to the adaptation of the local grid to accommodate the greater density and mix of uses. This dynamic process is called the “movement economy”.

2. METHOD AND DATA

The primary criterion used for selecting the case studies was urban grid form. This research aimed to compare the syntax performance of gridded and non-gridded urban form on predicting choices of residential locations and transport mode. However, the characteristics of gridded-ness or non-gridded-ness is not a duality; rather it is a continuous property where any city may fall at any point in a sliding scale ranging from a perfect grid to perfect organic urban form. Gridded cities have fewer but much longer streets, while non-gridded cities have a great number of shorter streets. Therefore, cities representing each kind of urban form were selected...
using the method illustrated in (Figure 1) below. After a comprehensive search of google maps of several cities and online public availability of city data, Boston and Pittsburgh representing non-gridded cities; and Lubbock and Salt Lake City representing gridded cities were selected.

Data were assembled from online open source databases of the respective cities and the US census bureau. Space Syntax topological and angular analysis of CAD drawn axial lines and street centerlines extracted from GIS maps were performed. The angular and topological analysis were performed using axial lines. In addition, angular analysis was also computed using road centerlines. Therefore, six configuration variables were extracted as illustrated in table 1.

<table>
<thead>
<tr>
<th>Measures of Syntax</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topological (Using axial lines)</td>
<td>Angular (Using segmented axial lines)</td>
</tr>
<tr>
<td>Integration</td>
<td>Topological Integration</td>
</tr>
<tr>
<td>Choice</td>
<td>Topological Choice</td>
</tr>
</tbody>
</table>

Table 1 - Configurational Variables

2.1 OTHER VARIABLES

This exploratory study involved an extensive lists of variables to investigate the predictive power of space syntax variables explaining transportation mode choice. In developing models of transport mode choice through multiple linear regression, two dependent variables, and 27 independent variables were selected. They are shown in table 2.
<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>1</th>
<th>Driving</th>
<th>The percentage of people in each census block group who chose to drive to work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
<td>Walking</td>
<td>Percentage of people in each census block group who chose to walk to work</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Land Use Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Population Density</td>
<td>Number of people per acre of each census block group</td>
</tr>
<tr>
<td>2 Street Density</td>
<td>Total length of streets (mile) divided by the area of census block group (Sq. mile)</td>
</tr>
<tr>
<td>3 Commercial Density</td>
<td>Area of commercial parcels (Sq. Mile) divided by the area of census block group (Sq. mile)</td>
</tr>
<tr>
<td>4 Building Density</td>
<td>Sum of figure-ground of all buildings in a block group divided by the area of corresponding block group</td>
</tr>
<tr>
<td>5 Age of Buildings</td>
<td>The median age of buildings in each block group</td>
</tr>
<tr>
<td>6 Rental Vacancy Rate</td>
<td>Percentage of vacant houses for designated for rent</td>
</tr>
<tr>
<td>7 Number of Rooms</td>
<td>Median number of rooms of residential buildings in each block group</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transportation Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Distance to PTS</td>
</tr>
<tr>
<td>9 Travel Time</td>
</tr>
<tr>
<td>10 Car Ownership</td>
</tr>
</tbody>
</table>
Socio-economic and Demographic Variables

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Race Black Percentage of Black population in each census block group</td>
</tr>
<tr>
<td>12</td>
<td>Race White Percentage of White population in each census block group</td>
</tr>
<tr>
<td>13</td>
<td>Hispanic Percentage of Hispanic population in each census block group</td>
</tr>
<tr>
<td>14</td>
<td>Family Households Percentage of family households in each census block group (family household is defined as a householder and one or more other people related to the householder by birth, marriage, or adoption) Percentage of non-family households in each census block group. Nonfamily households consist of people who live alone or who share their residence with unrelated individuals)</td>
</tr>
<tr>
<td>15</td>
<td>Non-Family Households Percentage of non-family households in each census block group.</td>
</tr>
<tr>
<td>16</td>
<td>Homeowners Percentage of housing units occupied by owners</td>
</tr>
<tr>
<td>17</td>
<td>Renters Percentage of housing units occupied by renters</td>
</tr>
<tr>
<td>18</td>
<td>Household Income Median household income in each census block group</td>
</tr>
<tr>
<td>19</td>
<td>Household Size Average household size</td>
</tr>
<tr>
<td>20</td>
<td>Gross Rent Median gross rent per month</td>
</tr>
<tr>
<td>21</td>
<td>Property value Median property value</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Topological Integration Average topological integration values of axial lines in each block group</td>
</tr>
<tr>
<td>23</td>
<td>Angular Integration Average Angular integration values of segmented axial lines in each block group</td>
</tr>
<tr>
<td>24</td>
<td>Centerline Integration Average angular integration values of road centerlines in each block group</td>
</tr>
<tr>
<td>25</td>
<td>Topological Choice Average topological choice values of axial lines in each block group</td>
</tr>
<tr>
<td>26</td>
<td>Angular Choice Average angular choice values of segmented axial lines</td>
</tr>
<tr>
<td>27</td>
<td>Centerline Choice Average angular choice value of road centerlines in each block group</td>
</tr>
</tbody>
</table>

Table 2 - List of variables used

2.2 DATA AGGREGATION

Most studies in space syntax had approached comparing the linear properties of axial lines with variables of corresponding streets. This method is emanated from the assumptions that the effect of syntactic properties of linear elements (streets) are limited to the spaces or properties adjacent to the corresponding streets only. On the contrary, this paper assumes that the effect of syntactic properties of a street transcends the adjacent blocks and extends to the surroundings (Berhie & Haq, 2015). To that end, a new method is employed using GIS tools. Here, aggregate configuration values of census block groups (the spatial unit of the study) are
taken into consideration to examine the effect of space syntax on choices of transportation mode and residential location.

As described earlier, the study began with the assumption that integrated areas attract retail and commercial activates which also become workplaces for a good number of people. It is also assumed that people who walk or bicycle to work will choose to stay close to their place of employment. Therefore, this study expects to find more walkers and bikers living close to integrated areas -- not necessarily in the integrated streets themselves. From this point of view, the investigation had to be focused on defined areas of cities rather than streets or axial line (Berhie & Haq, 2015). Hence, the space syntax values of linear features had to be converted to the study unit (census block group) through aggregation process. As indicated in Figure 2, average values of segments that are overlaid in each corresponding block group (in Figure 2b) is computed and the values are displayed in Figure 2c.

Figure 2 - Procedure of converting configuration values of axial lines to census block-group polygons

The colors represent integration values ranging between red indicating most integrated and blue most segregated areas

This was the method used to convert all variables into census block group of all four cities. Examples are shown in Figures 3 and 4 below.
Figure 3 - Illustration of converting topological integration values of axial map (left) to average integration values of census block groups (right) of non-gridded cities.
LOCATIONAL PREFERENCES AND TRANSPORTATION MODE CHOICE OF DIFFERENT SOCIO-ECONOMIC
GROUPS IN THE US: A space syntax included case study of two gridded and two non-gridded cities.

This study acknowledges that aggregating space syntax data to the census block groups may have weakened the linear descriptive power of axial lines. However, the distribution of axial values across the city remains similar, and can be visually clarified in Figure 4. The pattern and locations of the integration are similar in both axial and census block group maps. One real world advantage of this aggregation method is that it offers significant reduction of data collection costs and efforts because it allows the use of census data that are publicly available (Berhie & Haq, 2015).

Similarly, other variables that are not in the scale of census block-group were also converted to the common spatial unit of the study by the same aggregation method. This means the data that are available at smaller geographical features than census block groups are converted into average values for census block groups.

2.3 ANALYSIS

US census considers four modes of transportation. They are driving, walking, public transport and bicycling. Among them only choices of driving and walking are reported in this analysis. A series of statistical analysis were undertaken to select the best models for each transport mode. Since a large dataset were considered, the research began with a diagnostic test to detect multicollinearity problems between the independent variables. The observed collinearity was not similar in all cities; however, the common collinearities were between races types,
homeowners & renters, and the three integration variables. During each step of the collinearity diagnostics test, one variable with highest variance inflation factor (VIF) value was eliminated. The procedure continued until the VIF values of all variables were below 10.

The integration values computed in three different methods (topological integration of axial lines, angular integration of segmented axial lines and angular integration of road centerlines) showed strong correlation as (see Figure 5). This was not a surprise as the three integration variables are meant to measure similar configurational accessibility. However, this test enabled us to display their direct correlation with each other. In previous researches, it was not possible to test their direct correlation to each other since these three syntax variables use different type of lines. Their indirect correlation was only implied from the correlation each had with observed pedestrian and vehicular movement (Turner, 2001).

Figure 5 - Correlation between topological integration of axial lines, angular integration of segmented axial lines and angular integration of road centrelines.
Forward regression analysis was performed using SPSS statistical software to select the best model that most explain each of the four dependent variables. Two multiple regressions analysis (one for each transport mode) were performed in each city and a model for each dependent variable was selected with sets of significant independent variables. In addition, a series of simple linear regressions between different variables was performed to analyze the effect of configuration on housing location choice and its implication to the preference variations among homeowners & renters, and family and non-family households.

3. RESULTS AND DISCUSSIONS

As indicated earlier, this research had four goals. The first was whether space syntax is significant to explain transport mode choices for journeys to work places in addition to the variables previously identified in transport planning researches. Second, the study aimed to examine the effect of configuration on residential location choices, particularly to explore variance in residential location preferences among homeowners, renters, family and non-family households. Third, the study attempted to investigate the difference between gridded and non-gridded cities in their effect of configuration on transport mode and residential location choices.

Multiple regression analysis was performed to see if space syntax variables are selected within the models for both dependent variable (Walking and Driving). In addition, multiple simple linear regressions were done to examine the possible relationships of tenure, household type with configuration and travel mode.

3.1 EFFECT OF CONFIGURATION ON TRANSPORT MODE CHOICES

Two dependent variables (Driving & Walking) and 27 independent variables were included in our analysis. Factors affecting mode choices were analyzed using multiple regression models particularly forward and stepwise. One model with sets of explanatory variables was produced for each transportation mode (dependent variable). Both forward and stepwise regression methods produced identical results for all dependent variables in all four cities. The statistical results are discussed below.

3.1.1 DRIVING MODE CHOICE

Table 3 summarizes the multiple linear regression analysis results of driving mode choices. The adjusted R-square value for driving in Boston is 0.61, Pittsburgh 0.55, Lubbock 0.28, and Salt Lake City 0.61. This implies that about 61 percent variation of driving in Boston can be explained by regressing eleven variables listed in the model. Similarly, 55 percent of variation in driving in Pittsburgh is explained by nine variables listed in the model. In Salt Lake City 61 percent of variations are explained by the seven variables. However, only 28 percent of variations in driving can be explained by only four variables in the city of Lubbock.
### BOSTON ---- R² = 0.62, Adj. R² = 0.61

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.54</td>
<td>0.09</td>
<td>6.09</td>
<td>0.00</td>
<td>0.36</td>
</tr>
<tr>
<td>Travel time</td>
<td>-0.004</td>
<td>0.00</td>
<td>-3.74</td>
<td>0.00</td>
<td>-0.01</td>
</tr>
<tr>
<td>Topological integration</td>
<td>-0.32</td>
<td>0.10</td>
<td>-3.02</td>
<td>0.00</td>
<td>-0.52</td>
</tr>
<tr>
<td>% of Hispanic population</td>
<td>-0.10</td>
<td>0.04</td>
<td>-2.40</td>
<td>0.02</td>
<td>-0.18</td>
</tr>
<tr>
<td>% of family households</td>
<td>0.18</td>
<td>0.05</td>
<td>3.57</td>
<td>0.00</td>
<td>0.08</td>
</tr>
<tr>
<td>% of Renters</td>
<td>-0.16</td>
<td>0.04</td>
<td>-3.84</td>
<td>0.00</td>
<td>-0.24</td>
</tr>
<tr>
<td>Average household size</td>
<td>0.04</td>
<td>0.02</td>
<td>2.47</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Median number of rooms</td>
<td>0.03</td>
<td>0.01</td>
<td>2.77</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Car ownership</td>
<td>0.28</td>
<td>0.03</td>
<td>10.68</td>
<td>0.00</td>
<td>0.23</td>
</tr>
<tr>
<td>Median gross rent</td>
<td>-1E-04</td>
<td>0.00</td>
<td>-5.39</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Median property value</td>
<td>-9E-08</td>
<td>0.00</td>
<td>-1.99</td>
<td>0.047</td>
<td>0.00</td>
</tr>
<tr>
<td>Street density</td>
<td>-7E-04</td>
<td>0.00</td>
<td>-4.27</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

### PITTSBURGH ---- R² = 0.56, Adj. R² = 0.55

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Standard Error</th>
<th>t Stat</th>
<th>P-value</th>
<th>Lower 95%</th>
<th>Upper 95%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.94</td>
<td>0.11</td>
<td>8.3</td>
<td>0.00</td>
<td>0.72</td>
</tr>
<tr>
<td>Travel time</td>
<td>-0.003</td>
<td>0</td>
<td>-3.05</td>
<td>0.00</td>
<td>-0.01</td>
</tr>
<tr>
<td>Topological integration</td>
<td>-1.01</td>
<td>0.18</td>
<td>-5.59</td>
<td>0.00</td>
<td>-1.37</td>
</tr>
<tr>
<td>% of White population</td>
<td>0.07</td>
<td>0.03</td>
<td>2.19</td>
<td>0.03</td>
<td>0.01</td>
</tr>
<tr>
<td>% of Asian population</td>
<td>-0.23</td>
<td>0.11</td>
<td>-2.16</td>
<td>0.03</td>
<td>-0.45</td>
</tr>
<tr>
<td>% of family households</td>
<td>0.17</td>
<td>0.06</td>
<td>2.91</td>
<td>0.00</td>
<td>0.06</td>
</tr>
<tr>
<td>Median household income</td>
<td>1.6E-06</td>
<td>5.3E-07</td>
<td>3.06</td>
<td>0.00</td>
<td>6E-07</td>
</tr>
<tr>
<td>% of renters</td>
<td>-0.15</td>
<td>0.05</td>
<td>-2.99</td>
<td>0.00</td>
<td>-0.25</td>
</tr>
<tr>
<td>Car ownership</td>
<td>0.16</td>
<td>0.03</td>
<td>5.69</td>
<td>0.00</td>
<td>0.11</td>
</tr>
<tr>
<td>Median property value</td>
<td>-5.00E-07</td>
<td>0</td>
<td>-4.6</td>
<td>0.00</td>
<td>0</td>
</tr>
</tbody>
</table>
The models contain some common variables, for instance, travel time is significant to explain driving mode choice in all cities, while property value, car ownership, and percentage of family households were found to be significant in the models of three cities (Boston, Pittsburgh, and Salt Lake). Similarly, variables regarding socio-economic and demographic attributes such as household size, percentage of renters, and variables related to configuration i.e. topological integration and choice each appeared twice out of the four models. An interesting aspect to note on this research is that, space syntax variables were selected in all four models. However, topological integration of axial lines was selected in the models of Boston and Pittsburgh and topological choice of axial lines was included in the models of Lubbock and Salt Lake. These disparities seem to group the cities into two types, gridded and non-gridded. Accordingly, integration was important for non-gridded cities and choice for gridded ones.

A negative relationship between configuration variables and driving mode were found to be invariant in all cities. This suggests that keeping all other variables constant, people who live in topologically segregated neighborhoods of non-gridded cities (Boston and Pittsburgh) are likely to drive to work than people living in integrated areas. Similarly, workers who live in neighborhoods with lower values of topological choice in gridded cities (Lubbock and Salt Lake City) are likely to choose driving than people in areas of higher choice values.
3.1.2 WALKING MODE CHOICE
Table 4 summarizes the results of multiple regression analysis for walking choice in the four cities. Ten variables listed in the model explain 61 percent variation of walking in Boston, nine variables explain 50 percent variation in Pittsburgh, 4 variables explain 26 percent variation in Lubbock and 4 variables explain 40 percent of variation in Salt Lake City.

<table>
<thead>
<tr>
<th></th>
<th>BOSTON ---- R² = 0.62, Adj. R² = 0.61</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coefficients</strong></td>
<td><strong>Standard Error</strong></td>
</tr>
<tr>
<td>Intercept</td>
<td>0.18</td>
</tr>
<tr>
<td>Travel time</td>
<td>-0.01</td>
</tr>
<tr>
<td>Topological integration</td>
<td>0.63</td>
</tr>
<tr>
<td>Average household size</td>
<td>-0.04</td>
</tr>
<tr>
<td>Median number of rooms</td>
<td>-0.02</td>
</tr>
<tr>
<td>Median building age</td>
<td>-0.001</td>
</tr>
<tr>
<td>Car ownership</td>
<td>-0.13</td>
</tr>
<tr>
<td>Median gross rent</td>
<td>4.00E-05</td>
</tr>
<tr>
<td>Median property value</td>
<td>2.00E-07</td>
</tr>
<tr>
<td>Commercial density</td>
<td>0.1</td>
</tr>
<tr>
<td>Building density</td>
<td>0.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>PITTSBURGH ---- R² = 0.56, Adj. R² = 0.55</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coefficients</strong></td>
<td><strong>Standard Error</strong></td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.01</td>
</tr>
<tr>
<td>Travel time</td>
<td>-0.004</td>
</tr>
<tr>
<td>Topological integration</td>
<td>0.45</td>
</tr>
<tr>
<td>% of Asian population</td>
<td>0.2</td>
</tr>
<tr>
<td>% Family households</td>
<td>-0.24</td>
</tr>
<tr>
<td>Median household income</td>
<td>-1.20E-06</td>
</tr>
<tr>
<td>Average household size</td>
<td>0.07</td>
</tr>
<tr>
<td>Car ownership</td>
<td>-0.04</td>
</tr>
<tr>
<td>Median property value</td>
<td>3.70E-07</td>
</tr>
<tr>
<td>Commercial density</td>
<td>0.23</td>
</tr>
</tbody>
</table>
The models for walking choice include some common and significant variables. Car ownership and percentage of family household are negatively correlated to walking mode. Like the models of driving illustrated in section 4.1.1 above, topological integration was selected among other variables that explain walking in the non-gridded cities (Boston and Pittsburgh). Choice was included in models of gridded cities (Lubbock and Salt Lake City). Unlike the driving models of gridded cities, a slight difference is observed in walking models. The difference is that angular choice is selected in Salt Lake City while topological choice in Lubbock. Once again, topological integration is among the top variables that obtain 0.00 P-values implying that space syntax is important in predicting walking mode for these particular cities.

The positive coefficients of space syntax variables in all four cities imply that all other variables being equal, people who live in topologically integrated neighborhoods of non-gridded cities (Boston and Pittsburgh) are likely to walk to work places than people living in segregated areas. Similarly, workers who live in neighborhoods with higher values of topological choice in gridded cities (Lubbock and Salt Lake City) are likely to choose walk than areas of lower choice values.
Table 5 - Summary of space syntax variables selected in multiple regression models of driving and walking

<table>
<thead>
<tr>
<th>Transport Mode</th>
<th>Non-Gridded Cities</th>
<th>Gridded Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driving</td>
<td>Boston</td>
<td>Lubbock</td>
</tr>
<tr>
<td></td>
<td>Topological Integration (-ve)</td>
<td>Topological Choice (-ve)</td>
</tr>
<tr>
<td></td>
<td>Pittsburgh</td>
<td>Salt Lake City</td>
</tr>
<tr>
<td></td>
<td>Topological Choice (-ve)</td>
<td>Topological Choice (-ve)</td>
</tr>
<tr>
<td>Walking</td>
<td>Topological Integration (+ve)</td>
<td>Angular Choice (+ve)</td>
</tr>
</tbody>
</table>

Note: All angular choice in the table are meant angular choice of segmented axial lines.

Table 5 depicts the variation between gridded and non-gridded cities on the type of syntax variables selected in both modes of transportation. Integration was included in the models of both driving and walking for non-gridded cities while choice was selected for gridded cities.

3.2 EFFECT OF CONFIGURATION ON RESIDENTIAL LOCATIONS

Residential location preference variations are observed among different social and demographic groups of people. This included between homeowners and renters, and between family and non-family households. The preferences on residential locations have consistently affected the choices of travel mode. The reader should remember that family household is defined as a householder and one or more other people related to the householder by birth, marriage, or adoption. Non-family household consists of people who live alone or who share their residence with unrelated individuals. These two groups of variables are mutually exclusive and their relationship with any variable is always opposite.

3.2.1 HOMEOWNERS AND RENTERS

A choice of residential location is an intricate subject, which involve numerous factors. This study focuses only on location preferences in the context of street configuration. Particularly, we wanted to understand if configuration contributes to residential location choices and affects decisions of transport mode choices. From the simple linear regressions indicated in Figure 6, a notable asymmetry is observed between renters and homeowners in terms of their respective decisions in the context of configuration. Renters prefer to live in integrated areas while homeowners choose segregated neighborhoods. The two groups seem to consider different factors in their decisions on residential locations.

A remarkable discovery of this research is that location preference of homeowners and renters can be explained by configuration values in all four cities with no regard to city layout. Figure 6 shows that in all cities, renters positively correlate with topological integration values while homeowners do negatively. This implies that renters are likely to choose configurationally integrated neighborhoods, while homeowners prefer segregated areas. Eventually, this disparity in location preferences has revealed considerable differences in their choice of transport mode. This propensity for a specific mode of transportation is discussed now.
3.2.1.1 PROPENSITY FOR DRIVING

Figure 7 depicts that homeowners and renters have opposite preferences regarding driving mode. Homeowners are positively correlated with driving and renters negatively. Since homeowners prefer locations of configurationally segregated area, they are likely to drive more to work. On the contrary, renters seem to prefer configurationally integrated area and therefore, they tend to drive less. Although the strength of the relationships seems weaker in Lubbock, all relationships are consistent in all cities.

3.2.1.2 PROPENSITY FOR WALKING

Unlike for driving, renters positively correlate with walking and homeowners do negatively (Figure 8). This demonstrates that renters lean toward walking. This perhaps has to do with the preferences of residential location. Renters prefer to live in configurationally integrated areas. These areas are the same locations where commercial and retails migrate to take the economic advantages of movement attracted by configurational properties understood by integration. These land uses are also work places. In other words, renters are likely to live in close proximity to their work places making it easier to walk to their work.
3.2.2 DEMOGRAPHIC PATTERN

Statistical evidences are found that configuration has an effect on socio-economic and demographic patterns in our case cities. Variations are observed on choices of residential location and transport modes between family and non-family households in all cities.

3.2.2.1 CONFIGURATION, HOUSEHOLD TYPE AND NUMBER OF ROOMS

The findings (Figure 9) indicated that configurationally integrated areas are likely to be denser and have compact (smaller) housing units with relatively lower number of rooms. On the contrary, the negative correlation of integration with number of rooms and family household implies the segregated locations or neighborhoods are preferred by family-households; perhaps in part because it fits better to their need of higher number of rooms, flexibility, comfort, and auto travel convenience especially to those who have children. Number of rooms is very important factor for family households in their decisions of residential locations. This assertion can be supported by the fact that the correlation coefficient between number of rooms and family households is relatively big (0.43 Boston, 0.43 Pittsburgh, 0.3 Lubbock and 0.55 Salt Lake City) than correlation of integration with family households and number of rooms in all cities (Figure 9).
All P-values are less than 0.05

Figure 9 - Relationships between integration, household type, and number of rooms

Family household were observed to correlate positively with driving and negatively with walking (see Figure 10). This implies that family households are likely to drive more and walk less, and non-family households the opposite. This pattern of travel mode choice is consistent with their choice of residential location.
3.2.3 CONFIGURATION VS WALKING AND DRIVING

Driving and walking are related to integration in opposite ways. Figure 11 depicts that driving mode is consistently favored towards segregated areas in all four cities, on the contrary walking is preferred in integrated areas. However, the strength of relationships is stronger in non-gridded cities and weaker in gridded cities.

3.3 COMPARISON BETWEEN GRIDDED AND NON-GRIDDED CITIES

The major findings of this study is that first, space syntax is indispensable in studying the land uses and travel behavior of urban areas regardless of grid type. The theories that configuration first affect the movement and the movement rich areas of the system attract movement-seeking activities is confirmed in all cities (Hillier, Burdett, Peponis, & Penn, 1987). In all cities, statistically significant relationships between configuration and commercial density are found.
Second, multiple regression analysis displayed commonality within groups of cities and variations between gridded and non-gridded ones. Closeness (integration) measure of configuration was relevant to explain both walking and driving transport mode in non-gridded cities and between-ness (choice) for gridded cities (Berhie & Haq, 2015). Although the reason for this result is speculative at this point, this distinction will serve as an important beginning for future investigations and understanding the particular syntactic properties of gridded American cities (Ratti, 2004). We recommend additional studies to investigate why integration was important indicator in predicting transportation preference for non-gridded cities and choice for gridded ones.
REFERENCES


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DOES URBAN DENSITY FOLLOW CENTRALITY?

Empirical study on the influence of street network centrality on urban density and its implications for the prediction of pedestrian flows

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ABSTRACT

The aim of this paper is to explore the relationship between space syntax measures of network centrality and measures of urban density. To what extent do they correspond? How can space syntax parameters be optimized to account for urban density? We present findings from an empirical study where a range of urban density parameters are tested against space syntax measures of network centrality.

Space Syntax as an analytical framework has gained much attention due to its ability to predict complex behavioural phenomena such as movement flows or land use distribution using only little information about the environment. The movement network is modelled as a collection of visual axes and their relations, with no additional information about the environment included. This is rooted in the assumption that additional environmental variables, such as building density or land use, are either equally distributed or follow the centrality properties of the network (Hillier, 1999; Hillier 1996). Thus, all other environmental properties are treated as inherently embedded in the network configuration and therefore redundant. Indeed, empirical evidence shows that in many cases “over 60% of human movement can be predicted or explained purely from a topological point of view” (Lerman Rofe & Omer 2014).

Arguably, it is the extreme reduction of environmental complexity which has been the main innovation, but also the source of critical discourse about the Space Syntax method (Montello, 2007). Indeed, building densities and land use might sharply contrast with properties of network configuration, suggesting unresolved implications for the applicability of Space Syntax method as a movement predictor (Ratti, 2004).

Space Syntax analysis has been highly successful at interpreting aggregate movement flows in a network. However, this paper reflects the clear need to define under which conditions
Space Syntax analysis might be treated not only as measure of potential, but also as reliable predictor of human behaviour. For this purpose, we conducted a series of empirical studies testing the core assumption of the Space Syntax model about the multi-collinearity between configurational properties and a set of established urban density

KEYWORDS
Density, Network centrality, Pedestrian flow

1. INTRODUCTION
An ever-growing percentage of the world’s population lives in cities. This brings with it great challenges. As cities are forecast to continue to grow, the issue of how we plan urban densification in the future is a key issue (Borukhov 1978). This paper looks at the relationship between street network centrality, urban density and movement. Urban density refers to the amount of built matter in a unit of space (Rapoport 1975), and there are different ways of calculating it. A common measurement that is standard practice in the planning disciplines is the FAR (floor area ratio). However, the concept of urban density is multidimensional and the measure varies according to the parameters used in calculating it, i.e. by varying the unit of built form used “floor”, and/or by varying the unit of space used “area”.

Space syntax methods allow for movement flows to be modelled using only the properties of the network (Hillier & Hanson 1984, Hillier 1996). The street network is modelled as a dual graph, where the street segments are the nodes in the graph. The social use of space is explored by analysing the network as a graph, using graph theory-based measures of centrality. Two such measures are often used and will also be applied in this paper: integration (the mathematical measure of closeness centrality) and choice (also known as betweenness centrality). Aggregate pedestrian flow (Hillier et al. 1993), route selection of individuals (Emo 2014) as well as more complex social phenomena such as the distribution of land uses and the distribution of urban forms (Hillier 1996) have been shown to be related to network topology. Additional measures such as metric reach and directional reach have also been shown to relate to the distribution of land use and pedestrian flows (Ozbil, Peponis & Stone, 2011). Research has also examined how the distribution of building typologies, land use and network centrality is related to the liveability of cities (Ye & van Nes, 2013). The temporal interrelation between street network centrality and other measures of urban form such as block density, block area, building height and street width has been studied by Al_Sayed and Penn (2016). Whilst the distribution of urban density is held to be related to network topology, to date no research has systematically tested this by considering all its dimensions. This is the aim of our paper.

Our main research question examines what effect spatial configuration has on urban density. We examine this by comparing measures of network centrality against five dimensions of density as defined by Pont and Haupt (2010). A second research question explores what effect spatial configuration has on the distribution of movement attractors. This is assessed by comparing network centrality with building intensity.

We address a gap in knowledge linking the effects of network centrality and urban density (or the density of urban form). The currently untested assumption is that built form is either i) distributed equally or ii) follows network centrality. The relationship between density-centrality in planned and unplanned cities needs to be tested in order to: 1) support the theoretical foundations of space syntax; 2) identify the limits of the applicability of network centrality as a predictor of movement; and 3) identify methods that extend the applicability of the space syntax method.
2. METHODS

2.1 NETWORK CENTRALITY

Measuring the centrality of spatial networks has been widely recognized in built environment research as a valuable approach for understanding how urban systems are structured and used by their inhabitants. It has been shown that not only streets themselves are long lasting components of the urban realm (Marshall 2006), but also that their configurational properties remain stable over time (Strano et al. 2012). This approach is at the core of Space Syntax methods, which focus on how pedestrian flows are influenced by the structure of the environment, measured as a spatial graph (Hillier & Hanson 1984). The spatial configuration of the network is analyzed using graph theory-based measures of centrality, where the streets are nodes in the graph.

A particularly successful model of the street network for predicting pedestrian movement in the urban context is the “angular segment map” (Turner 2001, Hillier & Iida 2005, Turner & Dalton 2005, Varoudis et al. 2013). The spatial graph can be understood as a movement network consisting of vertices as visual axes1 divided at their intersections (segments) and their connections as edges weighted by the angular deviation between the adjacent segments (see Figure 1b, 1c). It assumes that people move in straight lines and tend to choose the cognitively shortest path between the origin and destination (Hillier & Iida 2005).

Since there are several ways of assessing the relative importance of each segment, the concept of centrality is multidimensional. In our research, we apply measures of closeness and betweenness centrality because of their theoretical and empirical relationship to how people behave and use the urban space (Hillier & Iida 2005). The former represents how close, or integrated, any two nodes are in the network. The formal definition of angular closeness centrality comes from Sabidussi (1966):

\[
C_c(p_i) = \frac{1}{\sum_k d_{i,k}}
\]

where \(d_{i,k}\) is the length of a geodesic (least angle change shortest path) between node \(p_i\) and \(p_k\) (Hillier & Iida 2005). Betweenness centrality measures how likely a path is to be chosen as a segment on a random journey through the network, and is a measure of flow. Betweenness is defined according to Freeman (1977) as:

\[
\text{Betweenness}(p_i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(p_i)}{\sigma_{st}}
\]

where \(\sigma_{st}\) is the number of shortest paths from node \(s\) to node \(t\), and \(\sigma_{st}(p_i)\) is the number of these shortest paths that pass through node \(p_i\). The axial map, which is the basis for the segment map adopted in this study, is constructed by drawing the minimal set of lines intersecting through all the convex spaces of the urban grid. For detailed instructions on how to draw the axial map see Hillier & Hanson (1984) and, on the algorithmic definition of the axial map see Turner, Penn & Hillier (2005).
2.2 DENSITY OF URBAN FORM

In general, the concept of urban density is restricted to a given boundary. Since any single density measure is “not nuanced enough to convey urban form” (Berghauser-Pont & Haupt 2010, p.79) we employ the following five dimensions of density, differentiating by the features of urban form being measured (Figure 2):

(a) Building intensity\(^2\) is a measure of density capturing the total gross floor area (F) per area of a plan (A). Similarly, it is the established approach among urban network research to treat the buildings or their floor area as a movement attractor (Hillier 1999, Stahle et al. 2005). Consequently, the building intensity can be utilized to answer the second research question about relation between network centrality and density of movement attractors.

\[
D_{BI} = \frac{F}{A}
\]

(b) Building coverage is a measure of the relationship between built area (B) and area of the plan (A). It identifies how developed an area is along a scale of zero (no development) to one (the whole area is occupied by buildings).

\[
D_{C} = \frac{B}{A}
\]

(c) Building height is the ratio between total gross floor area (F) and built area (B). It reflects the average number of storeys of a plan.

\[
D_{BH} = \frac{F}{B}
\]

(d) Spaciousness\(^3\) expresses the ratio between open space and total floor area (F). It reflects the pressure on the development of open space. The measure can be interpreted as the amount of open space on the ground per unit of built floor area.

\[
D_{S} = \frac{A - B}{F}
\]

\(^2\) Building intensity can also be found in literature under the alternative terms “Land use intensity”, “Floor space index” or “Floor area ratio”.

\(^3\) Equivalent to the Open Space Ratio.
Network density is a measure of the concentration of the network (I) per area of the plan (A). The unit of the measure is expressed as metres of network (represented as street centre lines) per square metres of ground area. Due to the focus of the study on pedestrian movement, only the walkable part of network has been taken into account.

\[ D_N = \frac{I}{A} \]

Figure 2 - Numerator and denominator of the five dimensions of density used in the paper: (a) Building intensity, (b) Building coverage, (c) Building height, (d) Spaciousness, (e) Network density (from Berghauser-Pont & Haupt 2010, p.94-96)

After specifying the numerator and denominator of each density measure, the boundary of analysis must be defined. This step is a critical part of any spatial analysis, since the definition of scale and shape of boundary has direct impact on the results of an analysis. In geography, it is known as the “Modifiable area unit problem (MAUP)” (Openshaw 1983) and has been approached by either avoiding arbitrary decisions in definition of boundary area, or at least systematically measuring its effects (Taylor, Gorard and Fitz 2003).

In our case, the boundary is supposed to capture the density of urban form around each network segment. For this purpose, the analysis boundary has been generated offset from the network segment with each point on the boundary equally far from the closest point on the segment. Regarding the size of the offset, it’s radius, we argue that instead of arbitrarily defining a single boundary offset, we can avoid the effect of MAUP by systematically studying this parameter. For this reason, we evaluate the effect of network centrality on the density of urban form for 14 different offset radiuses ranging from 20 m to 800 m (Figure 3a).

Once the boundary has been generated, three variables (Network length, Gross floor area, Built up area) are needed to calculate the five density measures and are assessed by considering only the urban form inside the boundary (Figure 3b).

Figure 3 - (a) 14 offset radiuses defining the boundaries of urban density (ranging from 20 m to 800 m). (b) Urban form for a given radius at a given segment
2.3 CASE STUDY WEIMAR

In this section, we present an empirical study conducted in the town of Weimar (Germany), which aims to measure the effect of network centrality on urban density and movement attractors. Weimar has a range of morphological patterns, from the organically evolved medieval town centre, to the regular grids of 19th century urban expansion areas and large slab-housing estates built in the 1970s (Figure 4). Furthermore, its size (64,131 inhabitants, 84.420 km²) makes it possible to analyse the entire town, eliminating the bias known as the “edge effect” resulting from the partial analysis of larger urban systems (Gil, 2015). Weimar’s size and compact shape also promotes walking as a main mode of travel, which fits with the focus and methods chosen in this study.

![Figure 4 - Example street network patterns and building densities found in Weimar. (a) Historical centre (b) Regular grid (c) Large housing estates](image)

2.4 DATA COLLECTION AND PROCESSING

The segment map used for calculating network centrality was drawn manually according to principles described in the method section, resulting in 3272 segments for the town of Weimar. To calculate the betweenness and closeness centrality for the network, the walking distance radius of the analysis had to be determined. For this purpose, we collected data on pedestrian flow at 120 locations throughout the whole of Weimar on three different days and three different times each day. Finally, the centrality measures were calculated using DepthmapX (Varoudis, 2012).

To calculate the density of urban form and network centrality, various data sources and software tools were used to collect, process and analyse the data. For the purpose of density calculation, the open source mapping platform OpenStreetMap.org was used to collect the data on building footprints, number of floors and street network. The density calculation was implemented and executed in the visual programming software Grasshopper for Rhinoceros. The density was calculated for the same set of 120 locations as used to calibrate the pedestrian radius of centrality measures. To examine the effect of network centrality on urban density, we assess all five density measure for each location in 14 different offset radiuses resulting in 8400 measurements. Finally, the statistical analysis and data visualisation was carried out in DecodingSpaces Rtools for Grasshopper (Abdulmalik & Schneider, 2017).

4 In the analysis of spatial networks, the ‘edge effect’ describes a bias in the analysis results as a product of the portion of the network included in the analysis (Okabe & Sugi, 2012). Different measures have different degrees of sensitivity towards the ‘edge effect’, mostly depending on the radius of the analysis (Gil, 2015). In this case study, we avoid the ‘edge effect’ by analysing the entire town. As no additional settlements exist within the boundary of the maximum analysis radius (2000m) from the edge of the town, extending the edge does not change the analysis results.

5 The current limitation of the study to 120 locations out of 3272 possible is restricted by the amount of computation time needed for the density calculations. The current implementation of density measures requires on average 50 seconds of computation time for one location and offset radius (depending mainly on the offset radius). The overall computation time for all locations and radiuses is approximately 23 hours.
3. RESULTS

To evaluate the main research questions concerning the effect of network centrality on urban density and movement attractors, we adopted (a) Space Syntax methods to measure network centrality and (b) five density measures as descriptors of the distribution of urban form. In this section, we introduce the results of the Weimar case study targeting the research questions and steps required prior to answering them. First, to calculate network centrality, we will identify the analysis radius corresponding to pedestrian travel. Second, we evaluate the impact of boundary offset radius on the five density measures. Third, we identify how many variables are required to describe the urban form. In other words, we ask if the original set of five density measures can be reduced. Knowing the dimensionality of urban form is of great importance since it determines the minimum number of dependent variables we are going to predict with network centrality as an independent variable. In general, the more variables required to describe the density of urban form, the lower its predictability by a single centrality measure. Finally, we model the relationship between network centrality as an independent variable and density of urban form as a dependent variable in order to answer the two main research questions.

3.1 NETWORK CENTRALITY

To determine the pedestrian radius of the network centrality analysis, we systematically investigated the relationship between radius definition (from 100 to 2000 m) and the ability of betweenness centrality to predict pedestrian movement (Figure 5). We assess the R-square as a measure of fit calculated in the linear regression model with betweenness angular centrality as an independent variable and average pedestrian flow as a dependent variable. To comply with the normal distribution criteria of linear regression, we logarithmically (LN) transformed both variables (Figure 5). The highest $R^2 = 0.491$ ($p$ value $\leq 0.001$) was found for a radius of 600 m (or a seven-minute walk). Furthermore, we conclude that the radius is more sensitive at a lower distance range, peaking at 600 m and then slowly falling towards a distance of 2 km with $R^2 = 0.058$ ($p$ value $\leq 0.05$).

Figure 5 - Distribution of movement potential (betweenness centrality R600) and measured movement (mean of all 9 counting sessions) before and after LN transformation. (a) measured movement, (b) measured movement after LN transformation, (c) Betweenness centrality, (d) Betweenness centrality after LN transformation. (e) Graph showing the relationship between the radius of betweenness centrality (in 100 m steps) and its ability to predict pedestrian movement (in $R^2$).

3.2 DENSITY OF URBAN FORM

We analysed the impact of boundary offset radius (ranging from 20 m to 800 m) on the five density measures. We examined how (a) variance and (b) the average value of each density measure change by increasing the offset radius. The change in variance across the offset radiiuses while keeping the mean constant can be seen as a measure of the ability to pick up differences in the distribution of urban form over the 120 analysis locations. Based on the results presented in figure 6a, we can conclude that for all five variables with growing analysis boundary, the
variance drops and became more homogenous. At an offset radius of 800 m, the variance of the density measures account for only 1 to 22% of what was measured at an offset radius of 20 m. Additionally, we observe that in four out of five cases (except the building height) not just the variance but also the average values are highly influenced by boundary radius. Here the most sensitive parameters are spaciousness and network density with 40–80% drop in comparison to the average values between a radius of 20 m and 60 m (Figure 6b). We conclude that beyond the 60 m radius, the average values remain stable with a fall-off in the case of Network density, Building intensity and Coverage and a slight increase for Spaciousness.

We conclude that the boundary radius parameter has an impact on both the middle and spread of distribution of the density measures and therefore has to be taken into account.

![Figure 6 - (a) Change of variance across radiuses relative to variance at radius 20 m. Measure at all radiuses were centred to mean = 0. (b) Change of average density across radiuses relative to average density at radius 20 m.](image)

Next, we evaluated the covariance between the five density measures to determine how many independent variables are required to describe the distribution of urban form. For this purpose, we examine the correlation matrix between the five density measures at all radiuses resulting in 140 unique correlations. Irrespective of the boundary radius, we can observe the same pattern of highly significant correlations between three variables (Building intensity, Coverage and Spaciousness) with Pearson’s correlation coefficient $|R| \geq 0.92$. Similarly, the Building height is independent of the other density measures across all offset radiuses. Furthermore, as illustrated in Figure 7, the relationship of Network density to Building height, Coverage and Spaciousness increases from $|R| \approx 0.26$ at radius 20 m to $|R| = 0.93$ at radius 800 m.

![Figure 7 - Pearson’s R correlation matrix between five density measures at offset radius 20 m and 800 m](image)

6 The 140 combinations are a result of all possible combinations of five variables multiplied by the 14 radiuses.
Given the high correlation between the density measures, we expect the set of five variables could be reduced. With this in mind, we applied a factor analysis using generalized least square (GLS) estimation and an oblique rotation (Geomin Q) to reveal a smaller set of latent variables behind the five density measures. Our criterion for determining the number of factors is that it should explain at least 95% of the total variance. We confirm that the distribution of the urban form can be described by two, respectively three factors depending on the offset radius. For offset radiiuses above 200 m, the two first principal factors account for 95% of the total variance (Figure 8).

![Figure 8 - Parallel factor analysis of five density measures across all 14 offset radiiuses showing the portion of variance explained by the first three principal factors. The red line marks 95% of cumulative variance.](image)

Furthermore, the factor analysis revealed that not only the number of factors but also the loading of the factors varies across the offset radiiuses. The latent factors suggested by the exploratory analysis of the correlation matrix result in three latent variables at boundary offset radius (a) below 200 m labelled as Build-up density (Building intensity, Coverage, Spaciousness), Network density and Building height and (b) at 200 m and above labelled as Projected density (Building intensity, Coverage, Spaciousness, Network density) and Building height (Table 1).

<table>
<thead>
<tr>
<th>Offset radius 20 m</th>
<th>Offset radius 800 m</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor 1</strong> Build-up density</td>
<td><strong>Factor 1</strong> Projected density</td>
</tr>
<tr>
<td><strong>Factor 2</strong> Network density</td>
<td><strong>Factor 2</strong> Building height</td>
</tr>
<tr>
<td><strong>Factor 3</strong> Building height</td>
<td><strong>Factor 3</strong> Building height</td>
</tr>
<tr>
<td>Network density</td>
<td>0.1</td>
</tr>
<tr>
<td>Building intensity</td>
<td>1.00</td>
</tr>
<tr>
<td>Coverage</td>
<td>1.00</td>
</tr>
<tr>
<td>Building height</td>
<td>0.00</td>
</tr>
<tr>
<td>Spaciousness</td>
<td>-0.98</td>
</tr>
</tbody>
</table>

Table 1 - Factor loadings for extracted three respectively two factors as suggested by the parallel factor analysis.

To summarise, we confirmed that the definition of an offset radius has an impact on all five density measures on their own, as well as on the latent variables hidden in the data. Furthermore, we find that in the case of Weimar, the set of five density measures could be reduced to two, respectively three factors based on the offset radius. We argue that this can be attributed mainly to the uniform distribution of building heights throughout the town of Weimar (4 storeys on average). Consequently, by keeping the building height constant, we can reduce the Building intensity, Spaciousness and Coverage to a single measure (build-up area per area of plan).
3.3 NETWORK CENTRALITY AS A PREDICTOR OF URBAN DENSITY

To quantify the effect of network centrality on the density of urban form and movement attractors, we conducted a series of linear regressions varying the three parameters that were previously identified as influential. First, the two different definitions of centrality (closeness and betweenness) were taken into account as predictors. By evaluating their individual and combined effects on urban density, we end up with three predictor parameters.

Next, we consider the boundary offset radiiuses by conducting the regressions across the whole range of radiiuses, resulting in 14 additional parameters.

Finally, at each offset radius, the urban form is described by five density measures. These could be reduced to a lower number of latent factors, however the composition of the factors and their number changes across the offset radiiuses. On the one hand, the latent factors reduce the overall number of dependent variables and so the overall number of regressions. On the other hand, these variables are unique for each offset radius, which makes it difficult to interpret the results. In particular, we are not able to follow the influence of the offset radius in relationship to centrality and individual density measures. For this reason, we regress on the five original density measures as described in the Method section.

Combining the variation of all three parameters (three predictors, five dependent variables across 14 offset radiiuses) we arrive at 210 unique regressions. To determine the effect of network centrality on urban density, we visualize the regression results by plotting the coefficient of determination (R squared) on the Y axis and the boundary offset radius on the X axis (Figure 9a). The results show that both centrality measures have a significant effect on four out of five density measures (except Building height). The strength of the effect varies based on the offset radius following the same pattern for all four significant regressions. This pattern can be described as an inverted U-curve starting with weak effects at small radiiuses, then continuously rising to a peak which is followed by a fall-off toward large offset radiiuses. The greatest deviation from this pattern can be observed at the smallest offset radiiuses between 20 and 40 m. The fluctuations in the fit of the model measured by R squared can be accounted for by the high variance and change of average value at lower radiiuses as discussed previously. Therefore, we suggest considering the offset radius 40 m as the smallest radius suitable for describing the density of urban form in Weimar.

When comparing the effect of individual centrality measures, we conclude that closeness centrality is in general a strong predictor, with a peak at 400 m offset radius, accounting for approximately 70% of the total variance of all four significant density measures ($R^2$ Building intensity = 0.685, $R^2$ Spaciousness = 0.705, $R^2$ Coverage = 0.685, $R^2$ Network density = 0.692 Network density). Betweenness centrality has its peak at 200 m offset radius, accounting for approximately 50% of total variance of all four significant density measures ($R^2$ Building intensity = 0.422, $R^2$ Spaciousness = 0.458, $R^2$ Coverage = 0.387, $R^2$ Network density = 0.547 Network density).

To evaluate the combined effect of both centrality measures on urban density, we conduct multiple linear regressions with closeness and betweenness centrality as predictors and five density measures as dependent variables across all offset radiiuses (Figure 9b). We realize that the effect of combined centrality follows the same pattern and reaches the same peak as in the case of closeness centrality as a single predictor (400 m, $R^2 = 0.7$).

7 From a morphological point of view, we find these high variations at locations where street width exceeds the offset radius defining the boundary of the density measurement area (Figure 6). In such cases, no urban form is detected resulting in extreme density values. We consider these measurements unreliable, since only a small increase in the offset radius can lead to an abrupt change in the description of the same urban form.
4. DISCUSSION AND CONCLUSIONS

The paper develops and implements a computational model for measuring the relationship between network centrality and urban density. We conducted an empirical study to test this for the case of Weimar. The empirical results show that network centrality is a strong and significant predictor of most aspects of the distribution of urban density, except the building height. Network centrality could also be related to distribution of movement attractors, however the strength of the relationship is highly dependent on the size of the boundary used to measure the density, the type of density measure and the definition of centrality.

Regarding the effect of different centrality measures on urban density, we found that closeness centrality is a better predictor than betweenness centrality (accounting for 70% and 50% respectively of variance in the data). This might be explained by the difference in spatial distribution between the urban density and the two centrality measures. Neither closeness centrality nor the density measures change abruptly between two neighbouring locations, allowing these variables to evolve together. Betweenness centrality, on the other hand, can vary highly from one street to another, contradicting how density is distributed in space.

By looking at the impact of the boundary offset radius at which density is measured, we summarise that the centrality of the movement network has only a marginal effect on the immediate neighbourhood (40 m radius). The effect grows constantly with increased boundary radius peaking at 400 m for closeness and 200 m for betweenness centrality, falling again as the radius increases to larger distances.

The low effect of network centrality on its close surroundings suggests that there might be other factors driving the distribution of urban density at a local scale. We argue that this scale is of special importance for applications modelling pedestrian flow and movement attractors. Not all attractors contribute equally to the attractiveness of movement destination, giving more weight to closer and more accessible ones. For this reason, the empirical evidence collected in the Weimar case study suggests that the loading of the network with movement attractors only marginally follows the pattern of network centrality. As a result, we suggest that the explicit modelling of movement attractors might significantly improve the results of any analysis depicting human movement in urban environments.

As can be seen, the distribution of urban density and the distribution of movement attractors could not be explained as a product of any single variable – measures of network centrality and additional explanatory variables were required. This finding is based on (a) the linear regression revealing that more than 30% of variance in density is caused by other variables than network centrality (Figure 9), and (b) the factor analysis of density measures (Figure 8) showing that at least two orthogonal variables are needed to describe density of urban form and therefore it couldn’t be fully predicted by a single centrality measure.
To identify those additional factors, we examined the spatial pattern of 120 residuals of the linear model predicting the density of urban form and movement attractors based on closeness centrality (Figure 10). By looking at the direction and magnitude of the residuals we can recognize the factors influencing either an increase or decrease of building intensity which cannot be explained by network centrality alone. In general, we could identify three different types of additional factors, all related to the planning of: (a) building complexes, large housing estates (b) functional zoning or (c) infrastructure.

On the one hand, we found that the allocation of large housing estates doesn’t follow the network centrality and in all cases the actual building density was higher than predicted. Together with building complexes, such as a university campus or a hospital, such large-scale developments are often planned at the edge of cities due to their space requirements. Consequently, the increased urban density doesn’t match the low network centrality of these segregated areas. On the other hand, the functional zoning of cities together with their infrastructural elements, such as railway lines, prohibits specific areas from being developed, causing lower building densities than predicted by network centrality.

Given all these points, we conclude that our findings on the relationship between network centrality and urban density are a first step towards defining the applicability and extending the predictive power of the space syntax approach.

Figure 10. 120 residuals of linear regression of closeness centrality on building intensity (offset 400 m). The size of the circle identifies the magnitude and the colour the direction of the residual. A negative residual means that the predicted density was lower than the measured one. Additional factors influencing density are marked as large housing estates (A1) Weimar Nord, (A2) Weimar West, (A3) Weimar Süd; University campus (A4); Cemetery (B1); Park am Ilm (B2); Railway (C)

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8 The spatial patterns of residuals are illustrated exemplarily and discussed through linear regression with closeness centrality as a predictor and building density at an offset radius of 400 m as the response variable. We have chosen this particular variation of centrality and density measures since it accounts for the strongest relationship between these two sets of variables.
REFERENCES


ABSTRACT

Urban diversity is a widely recognized concept used to describe vitality in cities and is often associated with cities that perform successfully both from an economic and social perspective. The concept of urban diversity was introduced to the broader public by Jane Jacobs, later inherited by the New Urbanism movement and has been extensively used in contemporary urban discourse. While theoretical definitions of urban diversity are manifold, measures that allow for a description of a more rigorous kind are less developed (Talen, 2006, 2008).

The aim of this paper is to identify fundamental variables of spatial form that could potentially contribute to urban diversity and socio-economic performativity. In particular, the paper investigates the concept of spatial capacity, that is, the impact of plot systems (i.e., land division) on urban diversity (Marcus, 2000, 2010; Sayyar & Marcus, 2013).

While the link to urban diversity is presented here as an essential starting point, the aim of this paper is to develop purely morphological measures of plot systems and to test if these measures can identify the difference among particular urban contexts. The study of the direct relation between spatial form and socio-economic performance is beyond the scope of this paper and will be presented in forthcoming studies.

The first part of the paper presents a theoretical framework to establish the fundamental morphological parameters of plot systems that can potentially contribute to urban diversity. The second part of the paper describes an empirical study of selected areas in Stockholm, Sweden, where essential morphological aspects of plot systems are explored and measured, using the proposed parameters of the plot systems.

Importantly, the plot systems are measured here in geometric terms, capturing size, openness and compactness of plots, and also in configurational terms through accessible number and diversity of plots using the Place Syntax Tool (Ståhle, 2008).

The paper is set within the framework of a bigger project aimed at developing and testing sound methodologies for measuring central variables of spatial form: density, diversity and distance (Berghauser Pont et al. 2017; Berghauser Pont & Marcus, 2015; Marcus & Berghauser Pont, 2015).
KEYWORDS
Urban diversity, plot systems, spatial capacity, area-based measures, location-based measures.

1. INTRODUCTION: THE FORGOTTEN VARIABLE OF DIVERSITY

Urban diversity is a widely recognized concept used to describe vitality in cities and is often associated with cities that perform successfully both from economic and social perspectives. However, it is not always clear whether diversity in this context refers to diversity in the spatial form of cities or diversity in socio-economic processes. This paper will briefly review various theories about urban diversity and then address how certain properties and attributes of spatial form may create and support socio-economic diversity. Based on the hypothesis that configuration of plot systems can potentially have an impact on urban diversity, several measures of spatial form will be proposed and demonstrated that can potentially grasp the differences among particular urban contexts and contribute to establishing a firmer link between spatial form and socio-economic performance.

The morphological measures discussed here are set within the framework of an international project called SMoL (Berghauser Pont et al. 2017) which aims to develop and test sound methodologies for measuring spatial urban form, focusing on the variables of density, diversity and distance that correspond to fundamental elements of urban space: buildings, plots and streets. (Berghauser Pont & Marcus, 2015; Marcus & Berghauser Pont, 2015) (Figure 1). Theory and techniques supporting such measurements related to distance and density are well developed and found first in Space Syntax (Hillier 1996), and second in Space Matrix (Berghauser Pont & Haupt, 2010). However, this is not the case with diversity. The point of departure is earlier research focused on the spatial capacity concept, arguing that land division into plots typically influences the number of owners of space within an area, which in extension also influences the number of owner strategies, which ultimately is likely to influence the diversity of land uses within an urban area (Marcus, 2000; 2010). Urban diversity is discussed here as an essential theoretical basis for the proposed morphological measures of plot systems, which is the aim of this particular paper. Further, this paper shows the test results using these measures and discusses whether they can identify differences among particular urban contexts. The relation between plot systems and socio-economic diversity is a next step of a more extensive study and will be explored in forthcoming papers.

Figure 1 - Three variables of urban form, corresponding to three basic elements of urban space and that can be measured using spacematrix, Space syntax or the concept of Spatial capacity. (Marcus & Berghauser Pont, 2015)

1 Spatial Morphology Lab (SMoL) is a three year project financed by Chalmers foundation, led by Lars Marcus and Meta Berghauser Pont
The first part of this paper presents a brief overview of urban diversity theories and a theoretical framework that allows for the establishment of the fundamental morphological parameters of plot systems that can potentially contribute to urban diversity. The second part describes an empirical study of selected areas in Stockholm, Sweden, where essential aspects of the plot systems are explored and measured with the proposed parameters. The concluding part summarises the results of empirical study of the proposed measures and lays the ground for future research: developing plot systems typologies and co-relating plot system configurations with socio-economic data in order to arrive to a more substantial theory about relation between spatial form and urban diversity.

2. THE CONCEPT OF URBAN DIVERSITY: CURRENT DESCRIPTIONS

The importance of a closer look at the variable of diversity in urbanism is demonstrated by the inconsistent use of definitions found within the literature. The idea of urban diversity was first introduced to the general public by Jane Jacobs (1961), who primarily looked at it from an economic point of view. It was extensively built on by the New Urbanism movement (Krier, 1984; Duany, Speck, & Lydon, 2010; Calthorpe & Van der Ryn, 1986), though rather in terms of how to create urban quality and attractiveness. Emily Talen (2006; 2008) presents an academic and thorough review of aspects of urban diversity, covering themes such as place vitality, economic health, social equity, and sustainability, and discusses alternative measures of diversity. Although the definitions of urban diversity in the literature are manifold, we repeatedly find them mixing morphological dimensions of diversity with socio-economic dimensions, where morphological dimensions often refer to small blocks and a mix of housing types, while socio-economic dimensions contain such parameters as a mix of uses/activities, and social/ethnical mix.

Hence, while fully recognizing that socio-economic dimensions such as mixed use may in themselves further generate urban diversity, it is essential, from the point of view of urban design, to understand how spatial form may influence and even generate urban diversity. We propose here that based on the concept of spatial capacity, that is, the division of land into different plots, we can bridge spatial form and socio-economic diversity. The ability of any spatial form to accommodate various uses over time, will here be understood as closely related to urban diversity as it enables diversity over time.

3. THE CONCEPT OF SPATIAL CAPACITY: THE ABILITY OF SPATIAL ARTEFACTS TO CARRY CATEGORICAL DIFFERENCE

The concept of spatial capacity, introduced by Marcus (Marcus, 2000, 2010; Sayyar & Marcus, 2013) describes the impact of land division, i.e., plot systems, on urban diversity. It proposes that the configuration of plot systems has a direct impact on the potential to host diverse owner strategies, and, consequently, uses (Figure 2). While here discussed on the urban level, we may see the principle at work in any artefact aimed at storing people, things or functions, whether they be cities, buildings or cupboards. The more such artefacts are divided into separate spaces, the more they create the opportunity to sort people, things or functions into a greater number of categories. As for any spatial form, this is not a deterministic relation but a conditional relation; we may not choose to sort people, things and functions according to this spatial form, but the conditions to do so are there.
MUL TIVARIABLE MEASURES OF PLOT SYSTEMS: Describing the potential link between urban diversity and spatial form based on the spatial capacity concept.

Related to this is the idea that a greater variety in size of plots can also have an impact on the degree of categorical diversity, due to differences in size of the things or functions. For example, in a vibrant central neighbourhood we usually find a diversity of activities that also vary in scale: a small grocery shop, an office building with middle-size companies and even an opera house. The same goes for a cupboard: a small drawer may be sufficient for the category socks, but a large one is needed for the category shoes, while small drawers would exclude certain categories, thus restraining diversity.

4. THE AMBIGUOUS CHARACTER OF PLOT SYSTEMS: STRADDLING INSTITUTIONAL AND SPATIAL SYSTEMS

The importance of the plot (also often referred to as ‘property’, ‘parcel’ or ‘lot’) as a fundamental element of urban form is well recognized within the field of urban morphology (Moudon, 1994; 1997; Whitehead, 2001). Conzen (1960) described the plot (not the block) as the basic element in the pattern of land division that works as the organizational grid in his ontology of urban form (Moudon, 1994). He also reflected on the dual character of the plot, being both a physical and a legal entity (Kropf, 1997). Furthermore, he introduced the concept of ‘burgage cycle’, that is the evolution over time of the built space bound by the spatial and legal framework of the plot – a concept directly related to the idea of adaptivity of urban form over time. The modification of plot and block patterns over time has been extensively studied by Siksna (1998) and Vialard (2012). According to Vialard (2012): there are certain block sizes that are more resilient to land use modifications over time than others. Smaller blocks within regular grids can better absorb changes, but at the same time, their geometric parameters do not allow for certain types of buildings and land uses because of their particular shape and size. Large-scale blocks are capable of accommodating a great variety of different uses, but their fragmentation or amalgamation caused by land use change can have a negative effect on the street network, because the size and complex shape often leads to the formation of dead-ends, incisions and blocks within the block (Vialard, 2012). Though Siksna and Vialard mainly discuss blocks, the hypothesis put forward here is that these observations may be relevant also on the scale of plots.

French typomorphologists also recognize the plot as one of the primary elements of urban space, along with buildings and streets (Moudon, 1994). Panerai et al. (2004) emphasize that the urban block should not be understood as a separate architectural element, but as a group of interdependent building plots. They stress the importance of a dialectical relationship between the plot and the street network (Panerai et al., 2004). The French school of urban morphology also discusses the role plot systems play in providing spatial and legal conditions for the evolution of built space over time (Panerai et al., 2004).

While the idea of the plot is ubiquitous in studies on urban form, its definition is often ambiguous; blending its different meanings of legal unit of control, land use unit and physical entity (Kropf, 1997). What is more, different countries have different property registrations, for example, in the United Kingdom no cadastral system exists and legal rights of use are organised instead in a system of freehold and leasehold properties. So, while recognizing the importance of the

Figure 2 - Illustrative diagram of the concept of Spatial capacity.
plot as the entity that provides a legal and spatial framework for action, it is necessary to define what the essential properties of a plot are that make it such an important element of urban form. A more general definition of a plot would be useful so that it could be applied to any urban context, taking into account fundamental properties of the notion of plots, while dealing with local differences separately.

Overall, we can define three basic aspects of plots. First, as a basic unit of control, the plot provides a fundamental link between spatial and non-spatial medium (Marcus, 2000; Kropf, 1997). Second, because a plot binds a building to a movement network, it serves as a connection between built space and space of movement (Panerai et al., 2004). Third, the plot provides the framework for building evolution over time (Conzen, 1960; Panerai et al., 2004).

All the above aspects are usually related to the idea of the plot as a private or privately owned space, corresponding to the common division of urban space into private or public, where plots, generally speaking, are private spaces, used for stationary uses supported by buildings, while the surrounding space, constituting the street network, is public, and primarily used for movement (Marcus, 2000). In reality it is not always that clear cut. For example, built plots can also be publicly owned and used for public facilities. Further, streets and what we perceive as public spaces are not necessarily publicly owned: they can be simultaneously privately owned and for public use. There are also cases where built plots can be transformed into public spaces as well as the other way around. Hence, dividing urban space into public and private and referring the latter to the system of plots is not always accurate.

The ontology of urban form used in this paper is based on the concept of generic function as introduced by Hillier (1996), which divides urban space into a continuous and publicly accessible space of streets and squares, primarily used for the generic function of movement on the urban scale, whether it be by car, public transport or on foot, and a discontinuous space constituted of blocks divided into plots that generally but not always are inaccessible to the public and primarily used for the generic function of long term occupation (Marcus, 2000).

5. METHODOLOGY FOR MEASURING PLOT SYSTEMS

5.1 CRITICAL ASPECTS OF PLOTS MEASURED THROUGH AREA-BASED AND LOCATION-BASED MEASURES

We will now discuss how to measure the plot systems as discussed in the prior sections, aiming for a method that effectively captures their morphological aspects that potentially can be related to socio-economic diversity. The aim is to develop a method both effective and fitting the adage of Occam’s razor: “Whenever something can be described in more fundamental terms, it should be done so” (Berghauser Pont & Haupt, 2010, p. 99). These measures need to capture the essential qualities of the plot systems as listed above: the potential to carry diverse owner strategies, the connection to movement space, and the framework for building evolution over time (Figure 3). We will proceed by testing potential measures one by one.
Firstly, related to the ability to carry difference, we will measure the number of plots and their diversity in terms of sizes. Secondly, related to the ability to connect buildings and the street network, the degree of openness of each plot will be measured, where the notion of plot frontage is essential, referred to as “plot or block face” by Vialard (2012), that is, the portion of the plot boundary where transition from the plot to the street network takes place (Vialard, 2012). This is measured as the relationship between plot frontage and total plot perimeter. Thirdly, based on previous findings of Siksna (1998) and Vialard (2012), it is suggested that the ability of the urban fabric to adapt to land use changes is related to the degree that plots are able to amalgamate into bigger plots or to divide into smaller ones. We assume that the degree of regularity of the plot is of importance for this adaptivity which we propose to measure as plot compactness.

These measures will be applied in two conceptually different ways: first, as area-based measures and second, as location-based measures (Ståhle, 2008) (Figure 4). Applying area-based measures, plots are measured geometrically in relation to each other, and each plot only stores information about its own parameters. Applying location-based measures is sensitive to the surrounding context and can be described as more life-like, since plots here are measured closer to how they may be perceived by moving agents; and each plot is here described by contextual information taken from surrounding spaces. Hence, this measurement does not concern only a particular geographical unit, such as a plot or a block, but the area accessible within a certain radius from a particular geographic unit¹. Location-based measures are here measured as accessibility through the street network, using the Place Syntax Tool².

Applying area-based measures, we measure and classify plot sizes, degree of plot openness to public space and the degree of plot compactness. Plot sizes are defined with GIS using the data classification method “geometric interval” which allows for a more fine-grain differentiation of plot sizes within urbanised areas. The degree of openness is measured as the ratio of total plot frontage divided by the total plot perimeter. The degree of plot compactness is calculated as the ratio of plot area divided by the area of minimum rectangular bounding of each plot. Plots with shapes closest to rectangles are regarded as the most compact (Figure 5).

1 For density, this mode of measurement has been extensively discussed (Berghause Pont & Marcus, 2014).
2 PST is a plugin application for the desktop software Mapinfo that combines space syntax with regular accessibility analysis in one tool.
MULTIVARIABLE MEASURES OF PLOT SYSTEMS:
Describing the potential link between urban diversity and spatial form based on the spatial capacity concept.

Figure 5 - Area-based measures of plot size, openness and compactness. Size categories are defined using natural breaks and geometric interval classification methods. Openness index rises to 1 when a plot does not have any neighbouring plots and falls to zero when a plot does not have any connection to movement space. For the compactness, index 1 shows the highest degree of compactness.

Applying location-based measures, we measure the accessible number of plots and the accessible diversity of plots meaning how different are plots in terms of sizes within certain reach. In order to calculate accessible diversity, plots are classified into several categories by size, after which accessibility to each category within 500m reach is measured. Finally, accessible diversity is calculated using the inverted Simpson Diversity Index\(^1\) (Figure 6).

Figure 6 - Location-based measures of plots accessibility (on the left) and accessible plots diversity (on the right).

\(^1\) In the Simpson Diversity Index the bigger the value of D, the lower the diversity. To make it more intuitive the value of D is subtracted from 1, so the values closest to 1 mean higher diversity.
5.2 DESCRIPTION OF CASES

In this paper, the proposed measures of spatial form are not related to socio-economic data, but a comparison is made between regularities in the plot systems captured by our new measures with known facts and characteristics of different urban areas. The investigation is made on the scale of the entire city of Stockholm, but a set of smaller areas with distinct morphological and socio-economic characteristics is chosen for comparison. These are: Östermalm, representing the city centre close to the CBD (case 1), Stureby, suburban single-family housing area (case 2), Årsta, a modernist multi-family housing area (case 3) and Slakthusområdet, a small-industry area (case 4) (see Figure 7).

The data on the plot systems used in the analysis is received from the Swedish Land Registry (www.lantmateriet.se). Because land plots from the Land Registry cover all types of land, including streets and water, the particular plot types have been extracted based on Bill Hillier’s concept of generic function (1996), where we defined the plot systems of interest to be ‘land used for long term stationary functions’ (according to the discussion above).

The comparative investigation between our new proposed measures in the chosen cases of distinct morphological and socio-economic character will begin with area-based measures and proceed to location-based measures.

Figure 7 - Map of a section of Stockholm showing accessibility to plots within 500m walking distance with the case studies marked. Data source: Swedish Land Registry.
6. DEMONSTRATION OF PLOT SYSTEMS MEASURES BASED ON COMPARATIVE CASE STUDIES

6.1 AREA-BASED MEASURES

Geometrical properties of the plots are analysed by classifying them into plot sizes, plot openness and plot compactness (see figure 8).

Simple comparison of plot sizes gives an overview of the principal differences between the four areas. The grain of the plot systems in Östermalm (case 1) is generally very fine but increases gradually towards the CBD to the South-West, where more “global” functions are located, reflecting the common trend in such areas for larger properties and land owners. Stureby (case 2) has a fine-grained pattern similar to Östermalm but its character is more isotropic. Årsta (case 3) and Slakthusområdet (case 4) show a great variety of sizes. In both cases groups of smaller plots are surrounded by large chunks of land creating ‘islands’ of smaller plots segregated from their surroundings, which contrasts with Östermalm, which demonstrated a gradual change in plot size from smaller to bigger. This similarity in plot sizes and their configuration in areas of very different land-uses is interesting to note.

Figure 8 - Area-based measures of plot systems in the four cases. Plot sizes (a), plot openness (b) and plot compactness (c).
The parameter *plot openness* is measured as the ratio between total length of street frontage of the plot and total perimeter of the plot. When a plot is located within another plot without direct connection to movement space, openness index falls to zero, and when a plot does not have any neighbouring plots, its openness index rises to 1. Groups of plots located next to each other and connected to movement space then have various average openness values. It is important to note that these indices are more applicable to plots in urbanised areas, and also more intelligible when analysed together with plot size. Stureby (case 2) has average ratios of this kind that gravitate towards 0.1, from which we can conclude that they have a relatively small proportion of street frontage. Östermalm (case 1) exhibits average values of openness between 0.5-0.6, which indicates a higher proportion of street frontage. Again, both Årsta and Slakthusområdet (case 3 and 4) demonstrate a high degree of plot openness, which may indicate a negative effect on the constitution of public space. A high degree of plot openness (close to 1.0) is reasonable when it concerns publicly accessible spaces, such as parks, but when such spaces are over-represented (typically in modernist areas) or fenced off (industries), their spatial openness may be described as overused, as in case 3, or underused, as in case 4.

In regard of *plot compactness*, we can clearly see that Östermalm, built following an orthogonal grid, is demonstrating the highest values of plot compactness. This means that this type of plot, according to the author’s hypothesis, in principle has the potential to be divided or merged to accommodate land use of different scales. Slakthusområdet, like many industrial areas, is delineated according to principles of broad functionality and the need of adaption, and also demonstrates a high degree of compactness. Stureby has average values in plot compactness, which can be explained both by the topography of the area, being rather hilly, and the “romantic” intentions of the architect behind the plan. Årsta, lastly, with the greatest variety in plot size, demonstrates the least compact plots grouped into highly complex patterns, which again may reflect the rather hilly landscape, but possibly also a low concern for the flexibility of the plot systems in the modernist era, driven by large public projects. However, the latter is something that would need further study.

From the first observations, through the combination of these parameters, a rich and informative description of the areas can be gathered, where certain things are as expected but others are surprising. For instance, while plots in Stureby and Östermalm are relatively similar in size, perhaps surprising and informative in itself, the latter are more compact and have greater openness, which suggests greater flexibility in terms of land use change and higher potential for interaction with public space, important for instance for retail. In Slakthusområdet and Årsta, on the other hand, it is surprising and informative that these are similar in the sense that both demonstrate a high variety of sizes and a high degree of openness; though plots in Slakthusområdet are more compact, which may allow for a greater flexibility.

In summary, it seems that although the measures presented above might be difficult to interpret when analysed separately, there is a potential for formulating multi-variable geometrical measures that enable a full description of the qualities of the plots. It is suggested that, similar to the multi-variable measures used in the spacematrix tool, developed for built density (Berghaeuer Pont & Haupt, Spacematrix: Space, Density, and Urban form, 2010), informative and revealing descriptions of plot systems can be arrived at.

### 6.2 LOCATION-BASED MEASURES

While the area-based measures of plot systems explored above capture the individual properties of each plot, location-based measures can describe plot systems in a more comprehensive manner. We here measure accessibility to plots, or, more precisely, how many plots can be reached within a certain radius (in this case 500m walking distance), and accessibility to diversity of plots, or, more precisely, how different in terms of size the plots are, again accessible within 500m walking distance (figure 9). It is important to note that the accessibility of plot systems of this kind, captures something different from, for instance, accessible built up area (i.e. accessible footprints). In order to make this clear, the accessible built-up area is shown along with the maps representing the accessible plots and accessible diversity of plots.
As seen from the overall map of accessible plots (figure 7), Östermalm and Stureby have the highest levels of accessible plots, where in the latter area this is equally distributed, while in Östermalm has a more hierarchical character emphasizing the centre. Slakthusområdet, although it generally has bigger plots, demonstrates a medium value in plot accessibility, which may be due to its rather regular grid structure which increases accessibility. Årsta, although it has plots similar in size to Slakthusområdet, demonstrates the lowest degree of accessibility. Based on the hypothesis that higher accessibility to plots may support higher economic diversity, we may tentatively conclude that this seems to be supported by the diverse central area of Östermalm, but not by the suburban single-family area of Stureby. It appears that something more is needed for socio-economic diversity than accessibility to plots. Interestingly, the great land use diversity of the industrial area Slakthusområdet seems to some degree to be captured by accessibility to plots, and the less diverse in terms of land use area of Årsta, also seems to confirm the hypothesis. However, these are very premature conclusions. The point rather is that we see how these measures start to capture some interesting properties of areas that call for further study.

Figure 9 - Location-based measures of the four chosen case studies. Accessible number of plots (a), and accessible diversity of plots (b) within 500m walking distance, are compared with accessible built-up area (c), in order to show principal differences between configuration of plot patterns and built form.
When it comes to accessible diversity of plots, the results are, in a way, inverted. Generally speaking, Årsta and Slakthusområdet demonstrate high values of accessible diversity, which is understandable given the complexity of the patterns earlier observed. Stureby, on the other hand, has the lowest values, while in Östermalm, the value increases towards the CBD. We have, however, reason to be a bit critical about this measure as it becomes apparent, and this might be problematic, that an area with 1 big plot, 2 medium sized plots and 20 small plots are considered as less diverse than an area with one plot in each category. The issue is that Simpson Diversity index ‘weights’ all the categories equally. So, translating this to urban functions, this would mean that an area with 1 theater, 2 banks and 20 shops will be considered as less diverse than an area with 1 shopping mall and 1 café.

7. CONCLUSION AND DISCUSSION

Based on these preliminary tests of new measures we see reason to develop multi-variable measures that enable a full description of the qualities of plots that described the potential of urban space to afford difference. While this relation, using socio-economic data, will be tested in following papers, this paper already supports the general idea and also gives hints on how to evaluate the different measures. Size, compactness and degree of openness to public space, all appear important when the individual qualities of plots are described. If the aim is to understand performance of whole neighbourhoods, accessibility to numbers of plots and accessibility to diversity of plots may be more effective. Equally important is the impact of what is measured, be it number or diversity of plots, as well as the scale of the investigation, that is, which radii are measured, and lastly, comparison between different scales. Many of these issues we will return to after the testing with socio-economic data in upcoming papers.

We do know that city centres usually perform as diverse and vital areas (socio-economically), since several scales are nested through the overlapping of local and global networks (Read, 2009), and fail in this respect when the local scale is insufficiently treated. It can then be assumed that while a high number of plots is necessary for establishing a fertile ground for socio-economic diversity to emerge, a greater variety in size is needed when local areas are scaled up from local to more globally performing centres. In other words, high accessibility to diversity of plots is important in situations of high plot accessibility, but makes less sense in situations with low plot accessibility. This again calls for the development of multi-variable measures, but also puts the question of the Simpson diversity index discussed earlier high on the agenda for further study. The lack of acknowledgement in the measure of the total amount of large or small plots in the whole system needs to be looked into. The development of a normalized Simpson Index, which would deal with these scalar issues and would be adapted to the specificities of urban spatial analysis, could be an interesting path to follow.

Within the bigger project, within which this paper is positioned, several goals are described that partly are based on the methodology and empirical studies introduced in this paper: developing a plot typology, relating the plot systems measures to other attraction measures (Marcus et al., 2017) and, studying the relation between these spatial variables and socio-economic data, in order to establish more fundamental theory linking use of space with spatial structures.

A plot typology including different variables as introduced in this paper can be developed using clustering analysis as proposed by Berghauser Pont et al. (2017). It could show, for instance, that small plots with low openness index and low accessible diversity index, are often found in certain urban areas and that non-compact plots of various sizes and with low value of plots accessibility are grouped in other urban areas. In a next step this could be related to socio-economic performativity where the first type might show low socio-economic diversity.

Besides relating to socio-economic data, we will also relate the measures presented in this paper to distance and density measures. Configurational properties of the street networks and building density have earlier repeatedly been demonstrated to play a decisive role in generating particular socio-economic outcomes, including socio-economic diversity. Including analyses of plot systems, as suggested here, may enhance these findings and add greater precision when it comes to the vital notion of diversity in cities (Marcus et al., 2017).
Studying the statistical co-relations between these spatial variables and socio-economic data, may also help to better distinguish which spatial variables are more important for socio-economic diversity and in what combinations.
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THE IMPACT OF SPACE SYNTAX ON URBAN POLICY MAKING:
Linking research into UK policy

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ABSTRACT
Space syntax as a discipline has important potential to influence urban policy making in a number of different fields, ranging from economic development to crime, urban sustainability and health. However, relatively few urban policy makers are aware of the potential of the discipline to both help diagnose urban problems, and to offer practical responses. Where space syntax policy does have influence, it is usually in the narrower context of specific urban design solutions in cities. This paper looks at the potential for space syntax to influence a wider set of policy fields, while considering what might need to be done within the discipline itself to make it more ‘policy facing’ – both by producing more robust evidence that is inter-disciplinary and timely, and by conducting follow-up impact evaluation, where space syntax-based recommendations have been applied in practice.

The UK is used as a case study for this research. Recent devolution to city government in this country has generated a need for new mayors and city authorities to develop ambitious, evidence-based and spatially-grounded strategies for future growth. There is significant appetite from national government officials, as well as elected city leaders and senior council officers, to think about the long-term future of the largest UK cities and to better understand their interrelationships with their surrounding city regions. However, initial discussions with policy makers reveal that in order for space syntax methodologies to contribute further to urban policy making, are a series of challenges must be addressed including: 1) a lack of clear messages and user-friendly literature setting out the rationale behind space syntax, and bringing together an evidence base linking the spatial configurations of cities with priority policy issues such as crime, poverty, economic development, health and environmental sustainability and; 2) a lack of evidence on the impact of space syntax interventions on the ground, with a dearth of long-term evaluation.

While the first of these issues is arguably a practical question of ‘translation’ (which could be addressed, for example, through the development of policy briefs), the second issue presents a more important challenge to the academic discipline of space syntax itself. In particular, how can the discipline become more effective at using research techniques that policy makers value
(e.g. regression analysis, meta-evaluations and cost-benefit analyses) and at documenting and analysing the impact of space syntax interventions?

KEYWORDS
Space syntax, evidence, devolution, policy, cities

1. INTRODUCTION
Since its development in the late 1970s, space syntax as a discipline has developed through both academic theoretical exploration, and through the practical testing of theories in ‘real world’ design problems through architectural projects. Its methodologies have therefore influenced practical design applications within architecture and planning. However, contact between space syntax and the broader urban policy world has been more limited. Given that space syntax reveals how spatial factors underlie urban policy areas – economic development, social inclusion, environmental policy, crime prevention, health and many others - it arguably has potential for wider influence on policy makers, beyond the context of urban design projects.

This paper looks at the potential for space syntax to influence a wider set of policy fields, while considering what might need to be done within the discipline itself to make it more ‘policy facing’ – in terms of producing robust evidence, that is inter-disciplinary and timely, and that also includes follow up impact evaluations of where recommendations born from space syntax have been applied in practice.

While there is a potential for space syntax to have greater policy impact on an international scale, the UK is used as a case study for this research. In this country, cities are gaining new, devolved powers from national government, creating increased interest from central government officials, council officers, local authority leaders (and future ‘metro’ mayors) in developing long-term urban strategies. Space syntax theories, methods and tools could influence these new UK policy audiences.

Initial conversations with UK policy makers have explored the way in which research influences policy beyond a spatial context, drawing in lessons that are applicable to space syntax. These conversations suggest that work is needed to increase the policy reach of space syntax and to ensure its research is policy-friendly. There is a lack of non-specialist literature, or papers available to audiences outside academia, exploring the rationale behind space syntax and its relevance to particular policy domains. The space syntax evidence base is also fragmented, and has not been synthesised for policy dissemination. Nor is there long-term evaluation for many urban design projects informed by space syntax, with a shortage of locally-relevant impact evidence. The latter is a particular problem, as policy makers seek reassurance before embarking on policy interventions through both quantitative evidence – changes to indicators over time (e.g. health statistics, crime rates, economic deprivation indices) – and qualitative case studies.

While arguably a number of these problems can be resolved through better ‘translating’ and consolidating the findings of the international space syntax academic community for a policy audience (through for example preparation of policy briefs), the above concerns also represent a challenge to the academic community itself. In particular, there may be a need for space syntax researchers to build ‘credibility’ with urban policy makers through more consistent use of research tools that are widely accepted in the policy community (such as multiple regression analyses and meta-analyses of literature); and making reference to other methodologies that the policy makers already finds credible (such as transport modelling). There is also a particular need for impact evaluations and international case studies that will help policy makers to understand the potential impact of space syntax informed interventions.

In order to further explore these issues, this article is divided into four sections: defining the problem – identifying where space syntax currently has policy influence, and where it does not; defining the opportunity for research in relation to policy making; reviewing space syntax evidence and potential influence in three policy areas (crime, health and social inclusion); and
2. DEFINING THE PROBLEM

As a discipline, space syntax currently has most policy influence in relation to the planning and design of the built environment, particularly in the UK and on large urban projects internationally. The official submission to the UK’s national Research Excellence Framework (REF), for example, primarily demonstrates the impact of space syntax through case studies on urban master planning and UK public spaces (REF, 2014).

Outside planning and urban design, space syntax has been less consistently influential on broader strategic policy development, city-level strategies, economic policies, inclusion/inclusive growth, health, crime or environmental policies. Despite the insistence of space syntax on the importance of linking parts of cities to the wider picture wholes, its influence is often piecemeal. Space Syntax Ltd. for example (a University College London spin-out company) has undertaken more than 1000 consultancy projects globally since it was founded in 1989. However, it tends to be consulted at project level, with the wider picture beyond the influence of a single project. Despite the size of the Space Syntax Ltd project archive, investigation has revealed limited evidence of direct policy influence via the many projects it has undertaken. Space syntax as an academic discipline has also traditionally been stronger in diagnosing spatial causes rather than demonstrating solutions. This does not automatically translate into policy impact, and the reasons for this are examined below.

3. WHERE IS THERE POTENTIAL FOR SPACE SYNTAX TO FURTHER INFLUENCE POLICY?

Spatial factors are integral to most urban policy areas. In all the fields discussed below, urban policy makers could arguably benefit from a clearer picture of how the built environment creates patterns of accessibility in cities, and how accessibility influences movement, and hence social and economic activity. Policy potential and challenges are summarised for a number of different sectors below, while this is followed by a more in-depth review of the literature for three policy areas: crime, health, and social inclusion. The list of policy areas is illustrative, not exhaustive, and indeed the potential for space syntax to influence policy will of course increase as the academic discipline itself evolves.

One area where space syntax could have a greater policy influence is economic development. For example, space syntax can show where economic development is more likely, revealing how economic and social activities tend to develop according to patterns of movement. Urban planners increasingly see the importance of mixing residential and commercial uses to create vibrant communities, and recognise that a polycentric distribution of economic activities, services and amenities across a city can promote greater social inclusion. For example, the Portland Development Corporation in Oregon, USA has made the development of ‘complete neighbourhoods’ central to their city strategy – areas where residents have safe and convenient access to essential goods and services, transport, connections to employment centres, community and open spaces within a 20 minute walk (Green et al., 2016). However, urban policy makers are not always aware of the role of the spatial configuration of the underlying street network in making such forms of ‘pervasive centrality’ possible. Space syntax can also help in the assessment of economic growth potential at the national scale through, for example, analysing the connectedness of places within the urban system (GO for Science, 2016). Serra et al. (2015), for example, find clear statistical associations at the scale of the entire UK between network structure, vehicular movement and the spatial distribution of several socio-economic variables, including productivity, affluence and employment. Such research could help in planning new housing, through revealing the areas of cities where accessibility to economic opportunity would suggest that housing density could be increased (GO for Science, 2016).

Space syntax analysis can also inform the policy drive to create more sustainable forms of urban living in tackling climate change. Hillier (2009) suggests that the generic spatial form of self-organised cities may minimise the movement needed to get from one part of the city to
the next, creating "naturally sustainable forms relating economic and social activity to space in a way which minimizes travel distances." Such ideas may inform future investment in housing and infrastructure, reducing the development of car-dependent urban forms.

Space syntax analysis routinely identifies areas of cities that are more segregated, and less connected to urban movement flows, which urban policy makers could take into account when planning public transport investment. This is not a straightforward process – public transport networks tend to follow already accessible routes (see Scheurer and Curtis, 2008; Vieira and Medeiros, 2012) and Bertaud (2004) points out that it can be difficult to bring public transport to less dense areas of the city, with too few passengers to be cost-efficient – but space syntax could help to better inform the debate.

Space syntax analysis may also help to guide urban regeneration projects, shedding light on the reasons that some physical regeneration schemes are more successful than others. In particular, a focus on how space is organised between buildings may be more important than changing the aesthetics of the buildings themselves. Space syntax also suggests that any local intervention should be complemented by looking at how more deprived areas are linked into the broader city. This means that urban regeneration needs to be carried out as part of more comprehensive city level strategies, which for example also promote accessibility to employment and education across the city as a whole.

Given that space syntax reveals spatial issues arising from the built environment, it is often assumed that its only impact can be through changes to this built environment. However, this is not necessarily the case. Major redevelopment is not the only tool available to policy makers. Funding for capital investment is limited, and Bertaud (2002) points out that changes to the underlying street structure of cities are relatively rare, with a strong degree of path dependency associated with city spatial configurations. However, by recognising how spatial dimensions influence city phenomena, policy makers may be better placed to counteract or compensate for spatial effects, perhaps using non-spatial solutions. One example would be the employment of park wardens, for example, to increase surveillance in spaces that are not well-served by national surveillance from surrounding residences.

4. SPACE SYNTAX EVIDENCE AND POLICY – LITERATURE REVIEWS

Three areas where space syntax would seem to have a particular potential to influence urban policy making are crime and safety; health and social inclusion. A summary of the evidence that might usefully inform urban policy is included for each area below.

4.1 CRIME AND SAFETY

There are two competing schools of thought on how urban design influences crime and community safety (Hillier and Sahbaz, 2009, 2012): 'new urbanism', influenced by Jacobs, who felt that open and permeable mixed use environments were the safest (1961); and that of Newman, who developed a concept of 'defensible space' (1973), arguing that through movement should be restricted so people could gain more 'control' over their territory.

Space syntax has shown that both these perspectives have their strengths and weaknesses, with the relationship between crime and urban morphology complex and subtle. Evidence for policy makers has been sporadic and inconclusive (Hillier and Sahbaz, 2009), with the situation complicated by the many different types of crime, likely to take place in different urban environments. A breakthrough came in 2009 when a large-scale, multivariate space syntax study of crime in a London borough, provided detailed findings that could be particularly helpful to policy makers (Hillier and Sahbaz, 2009, 2012). However, the authors acknowledge the need to follow this study up in other locations.

Some key findings emerge from the literature which could be pertinent to urban policy makers. The more neighbours on a street segment, regardless of street type, the safer you are according to Hillier and Shu, 2000; Hillier and Sahbaz, 2009; Hillier and Sahbaz, 2012. The existence of a local 'virtual community' of people who regularly use the same spaces (Hillier, 1999) appears
to be important in reducing crime risk. Dwelling type is a critical factor in vulnerability to residential burglary, with flats being the safest type of residence, and detached houses the least (Hillier and Sahbaz, 2009). Street robbery and violent crime occur more in busy city streets and in their adjacent streets (Hillier and Sahbaz, 2009; Summers and Johnson, 2016), but for street robbery this effect varies with time of day (Hillier and Sahbaz, 2012). Mixed-use streets with few residents are particularly at risk (ibid). Local movement reduces risk, while larger-scale movement can increase it. For this reason, residential areas need to be designed to structure local movement, while managing larger-scale movement. Safer dwelling types can be used to balance ‘eyes on the street’ with ‘eyes from the street’ (Hillier, 2004; Hillier and Sahbaz, 2009, 2012).

There are ‘flip over effects’, however, where normally safe types of urban design become dangerous in particular contexts – for example, more integrated streets usually have lower burglary risks, but with secondary exposure through alleys or adjacent open areas, or basement access, they can become vulnerable (Hillier and Sahbaz, 2012). It is also not easy to make categorical assumptions about the relative safety of particular urban configurations. Earlier space syntax analysis found that traditional street patterns outperformed more ‘modern’ hierarchical layouts (Hillier, 2004). However, simple linear culs-de-sac with good visibility between dwellings, in a through-street pattern, can be very safe (Hillier, 2004, Hillier and Shu, 2000).

4.1.1 POLICY RELEVANCE

One factor which may make it easier for space syntax to have an influence in this field is that spatial vocabulary is already accepted. The ‘secure by design’ idea is well known, and the built environment is acknowledged to be important for crime and community safety. Ideas such as ‘permeability’ have been broadly picked up in policy literature, even if the complexity of the issues is not always well understood. Another enabling factor is that space syntax has produced robust large-scale studies, including multivariate and regression analysis, which helps to identify the relative importance of space syntax against other variables (e.g. Nubani and Wineman, 2005; Baran et al., 2007; Hillier and Sahbaz, 2009; Sohn et al., 2010; Hillier and Sahbaz, 2012), in addition to meta-analyses of the existing literature (Marzbali et al., 2010). One paper has completed a cost/benefit analysis (Chiaradia et al., 2009).

Similarly, it can be relatively easy for policy makers to both measure the problem and to assess the impact of proposed solutions (i.e. through a reduction in crime rates). For example, an initiative in Gosnells, Australia set the target of a 10 per cent crime reduction over three years following the use of space syntax techniques.

A further enabling factors is that policy responses do not necessarily need to involve investment in changing the built environment, but could include, for example, an increased focus on policing or surveillance in at-risk areas.

A barrier to policy adoption is the fact that policy makers often rely on statistical analysis of crime which shows ‘hot spots’, based on area analysis, rather than streets and dwelling level research, which is only accessible, anonymised, with special permissions (Hillier and Sahbaz, 2012).

A further barrier, as identified above, is the complexity of findings. Previously in the UK, Newman’s ideas about defensible space dominated policy discussions, strongly informing the popular ‘Secure by Design’ scheme (Cozens and Hillier, 2008). Cozens and (David) Hillier (2008) bemoan the fact that the ‘Crime Prevention through Environmental Design’ (CPTED) approach often represents conflicting views, drawn on piecemeal by policy makers and police without reference to local circumstances or an understanding of wider connections to the city. For example, while Hillier and Sahbaz (2009, 2012) highlight the benefits of local through movement, Armitage (2011) continues to advocate its restriction, even by gating local communities.

4.2 HEALTH

Space syntax researchers have engaged extensively with the causes of poor public health. Wineman et al. (2012 and 2014) worked with public health authorities in Detroit, USA, to show how space syntax could help assess the contribution made by street networks to complex social problems, including levels of physical activity. Zimring et al. (2005) showed how space syntax could help address obesity levels in the USA, by designing in physical activity, as did Nicoll (2007) through building layouts.

Researchers have demonstrated the direct relationship between the spatial characteristics of street networks and pedestrian movement in locations including London (Hillier et al. 1993; Desyllas and Duxbury, 2001); Seoul, South Korea (Kim and Sohn, 2002); Greek cities (Peponis et al. 1989); Atlanta, USA (Peponis, Ross, and Rashid, 1997); Dutch cities (Read, 1999).

Space syntax measures have been applied to understanding how design can encourage walking. Baran et al. (2008) used space syntax to compare walking patterns in two USA neighbourhoods, one a conventional suburban layout and the other a more ‘walkable’ New Urbanist development. They showed that the more integrated routes in the latter were better used by walkers.

Research has applied this understanding to public health. Watts et al. (2015) and Sarkar et al. (2013) in Wales, have linked more walkable, connected neighbourhoods with lower cognitive decline and psychological distress - important for understanding how the built environment can help manage illnesses such as Alzheimer’s. Joseph and Zimring (2007) showed how routes could be designed to enable walking in US retirement villages.

Physical activity is frequently associated with proximity to public space, but Koohsari et al. (2013) demonstrated that proximity to public open spaces did not predict use, but a more sophisticated understanding of how public spaces relate to the street network could predict public health benefits.

Space syntax has been used for many years to analyse healthcare buildings. Researchers have modelled hospital users’ wayfinding, from selected hospital corridors to entire hospital complexes in Atlanta, USA (Peponis et al. 1990; Peponis et al. 1996; Haq, 1999); anonymised American cities (Haq and Zimring, 2003); virtual American hospital environments (Haq et al. 2005); and in Minnesota, USA (Lu and Bozovic-Stamenovic, 2009). Tzeng and Huang (2009) used space syntax to designing signage systems for deep hospital layouts. Alalouch and Aspinall (2007 and 2009) measured privacy in UK hospital wards spatially, revealing that patients unexpectedly prefer rooms with more surveillance. Hanson and Zako (2005) quantified links between the layout of care homes in the UK and activity among residents.

Researchers have investigated how hospital buildings can support staff (Hendrich et al., 2009; Heo et al. 2009; Cai and Zimring, 2012), showing that space syntax can predict the movement of nurses in US hospitals, providing information to design for more effective communication. Lu (2010) demonstrated the importance of visibility on the operation of nursing units. Haq and Lo’s (2012) guide helps non-specialists apply space syntax to hospital layouts.

Pachilova and Sailer (2013) showed how different UK layouts affect the way that staff and patients communicate, and linked quality of care with smaller, simpler hospital campus layouts (Pachilova and Sailer, 2015). Setola (2009) showed how space syntax could be used to improve hospital circulation, increasing efficiency and reducing costs. Kim and Lee (2010) recommended hospital layout typologies most likely to deliver best whole life value.

4.2.1 POLICY RELEVANCE

Building scale findings could change hospital and care homes design, and at the urban scale, space syntax could contribute to the policy drive to improve health outcomes for an ageing population. In particular, the creation of ‘walkable’ healthier cities is becoming a policy priority, as tackling cognitive decline among older people (Watts et al., 2015).

The breadth of space syntax research on public health policy is both a strength and a weakness. The strongest evidence relates to the design of healthcare buildings, where substantial work
evidences the importance of spatial factors in creating the best environment for patients and staff. However, international evidence is not collated, nor is it influential beyond the countries where it was produced with senior NHS practitioners sceptical of international best practice examples (Simmons, 2015). In the UK, the NHS Health Building Notes series provides best practice design guidance for many types of hospital building and building elements. Formalised guidance is a clear opportunity to establish spatial analysis as a required feature of UK healthcare design.

Healthy urban design can also be informed by space syntax. At building scale, developers and landowners may gain commercial advantage from healthier spatial layouts, perhaps in combination with other space syntax evidence on productivity benefits for office design.

At urban and neighbourhood scale, work on more sophisticated methods of understanding green space usage would, if more widely known, be relevant to many local authorities who are facing budgetary pressures to justify the upkeep and management of parks and green spaces. Space syntax research into the spatial factors influencing distribution of poverty is historically specific, but could be more persuasive if also applied to contemporary data.

4.3 SOCIAL INCLUSION AND DEPRIVATION

4.3.1 POLICY RELEVANCE

Data available from the Office of National Statistics (ONS) provides detailed information on deprivation and ethnic mix (which by extension may be used to describe BAME residential clusters) at the level of Lower Layer Super Output Area (LSOA). While this provides a spatial overview of the distribution of deprivation etc., it misses granular phenomena i.e. the way the socio-economic character of a street may differ considerably from another adjacent to it in the network. Space syntax methods are equipped not only to analyse space at a street by street scale but also to relate social data to spatial configuration. This allows better understanding of how spatial form influences accessibility, which effects the use of space, the distribution of urban services and the economic well-being of a community – all areas of clear relevance to city leaders.

5. DEFINING THE INSTITUTIONAL CONTEXT

The UK has been chosen as a case study for this research, and in particular for an exploration of the institutional context for how space syntax findings might have more influence. Although the potential for Space Syntax to become more policy making is obviously international, the UK seems to offer particular current promise given recent devolution of new responsibilities to UK city mayors. The existence of Space Syntax Ltd., Spacelab and other spin-off consultancies also provides a potential link between academic researchers and policy makers.

5.1 WHAT IS THE URBAN POLICY CONTEXT IN THE UK?

The UK has traditionally been amongst the most centralised OECD states (Centre for Cities, 2014). However, in recent years the constitutional and policy context, particularly around cities, has moved towards decentralisation. The process, which started with City Deals in 2011, means that substantial changes continue to take place in the way the UK’s metropolitan areas are run and financed. The speed and scale of change has placed the UK at the forefront of international urban policy discussion.

The recent period of decentralisation began with two ‘waves’ of City Deals, totalling 26 cities across the UK. Initially these provided limited devolution of powers or funding for discrete projects, without any devolution of fiscal responsibility. By 2014, these had been succeeded by a total of 39 Local Growth Deals which provided funds to Local Enterprise Partnerships for projects that benefitted the local area and economy (Department for Communities and Local Government et al. 2014).
Most recently, Devolution Deals have begun transferring powers, funding and accountability for policies and functions previously undertaken by central government. Devolution Deals have two particularly notable features: firstly, they are based on functional economic areas, causing an aggregation of local authorities into new combined authorities at city-region or ‘metro’ scale. Secondly, a condition of Devolution Deals was the implementation of an elected Metro-Mayor to provide accountable leadership for new responsibilities.

Each agreement is bespoke, based on local proposals and geography (NAO, 2016), and progress is difficult to track. Nor is it known how many regions will elect metro-mayors in 2017 (Elledge, 2017). While the ‘deals’ have commonalities, there are also substantial differences and some areas are without any sort of deal, resulting in more fragmented governance structures across geographies and policy spheres.

Alongside decentralisation there is a partial re-emergence of regional-scale strategic planning and thinking in England, undertaken by central government instead. Bodies such as the National Infrastructure Commission have already begun to think across boundaries at the regional scale in specific areas, and the Government’s ‘place-based’ industrial strategy could enhance this trend (National Infrastructure Commission, 2016; PM’s Office et al. 2017).

The overall direction has been towards decentralisation of powers; the interventions described above could create an entirely new pattern of subnational government in England, with ramifications not yet fully understood by policymakers or by academics.

5.2. HOW DOES EVIDENCE INFLUENCE UK POLICY MAKING?

As a case study, the UK provides examples of the way that evidence, such as that produced by space syntax researchers, can fit into the decision-making processes and frameworks used by policy makers. Public servants in the UK have been obliged to practice evidence-based policy-making for 20 years (Schweber et al., 2015). An evidence-based approach has been championed by successive governments, and the Coalition established What Works Centres to support evidence-based interventions in the social policy arena (Cabinet Office, 2013). Evidence-based policy has been defined as where “good evidence is put to the forefront by those designing or implementing a policy or intervention to inform the decisions that they make … considering all of the available evidence” (The Alliance for Useful Evidence, n.d.). Cairney (2016) describes it as a “vague aspirational term, rather than a good description of the policy process.”

Despite years attempting to make policy more evidence-based, it is still regarded as an area of weakness by ministers and civil servants (Rutter, 2012). Rutter identifies both supply and demand issues in relation to evidence-based policy making. From the supply side, a lack of timely research and good data, as well as academics experiencing difficulty engaging in the policy process, were identified as contributory factors. Conversely, on the demand side the culture and incentives of ministers and civil servants militated “against more rigorous use of evidence and evaluation” (Rutter, 2012, p.4).

Some policy areas appear to be more open to evidence than others, perhaps making it easier for disciplines such as transport modelling or economics to achieve policy influence. Warwick (2015) notes that built environment policy-making in particular can be “messy”, while Simmons observes that in relation to the built environment “expediency, emotion or ideology play a role as often as the systematic and rational application of evidence” (Simmons, 2015, p.407).

It is therefore unrealistic to expect evidence to be drawn on wholeheartedly in all policy decisions, as there are “many subjective forces [to] counterbalance objectivity”, particularly where the built environment is concerned (Simmons, 2015, p.407). These forces could be caused by factors including cultural differences, ideologies, political considerations or risk aversion. In recognition of these political and subjective limitations, it may be more effective for space syntax to engage with the ‘policy process’ of policy formation and definition, rather than with particular policies or policy decisions (Simmons, 2015).

Discussion of evidence-based policy is strongest in relation to national government policies, and much less prominent in relation to metropolitan strategy, policy and practice. However,
the emergence of new forms of metropolitan governance and leadership in the UK are an opportunity to consider how more evidence-based approaches to policy formation and governance could be introduced at the urban scale.

6. CONCLUSIONS

This paper has assessed the scope for the discipline of space syntax to increase its policy influence, setting out ways in which the discipline could become more ‘policy facing’.

There is clear potential for space syntax to influence many urban policy areas. However, translating analysis into policy will not always be straightforward. Space syntax often produces nuanced findings, which do not always create clear policy messages. Further, policy making is not a simple process, with new policy interventions often the result of trade-offs between competing priorities, including cost.

As a research methodology, space syntax has many strengths: its versatility, its cross-cultural relevance to urban form, its extensive and growing research base, and its youth as a discipline. However, space syntax also needs to address weaknesses that reduce its impact on policy. Some are common academic problems: self-contained conversations, work hidden in academic journals, a reliance on specialist language, and a lack of material designed for practical application. The space syntax community is both a strength and a weakness, with many international projects but also a lack of focus on objectives beyond them, and a failure to evaluate space-syntax based interventions. The term space syntax itself is also a barrier, implying exclusive, technical, academic and proprietary characteristics.

This paper identifies opportunities as well as problems. The UK policy landscape case study identifies new audiences with a particular interest in understanding urban dynamics in new ways and at different scales to traditional policy audiences. Simple literature reviews from the perspective of policy audiences clearly demonstrate the wide relevance of the existing research base. They highlight a research agenda for space syntax; knowledge gaps which, if filled, would contribute to the impact of space syntax on practice. There is also a clear need for evaluation of urban design projects already applying space syntax techniques, to provide persuasive, policy-focused evidence of impact.
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THE IMPACT OF SPACE SYNTAX ON URBAN POLICY MAKING:
Linking research into UK policy


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ABSTRACT

The subject of integration between national territories in South America became urgent after the creation of MERCOSUR economic block in 1991, what gave rise to several transnational cooperation projects. The original associates -Argentina, Brazil, Paraguay and Uruguay - have been sharing robust historical cross border exchanges. Following global trade trends and focusing on the opening of Eastern markets for South American goods. Oceanic connections became vital in reducing transportation costs, intensifying cargo flows along routes linking production poles to seaports. Diminishing export costs is priority to all South American national states, therefore the improvement of infrastructure systems connectivity and cooperative planning strategies are now priorities in order to turn the Block competitive in global markets. Cargo traffic through South American road network at regional level is prevalent, since territorial planning coincided with the diffusion of motor vehicles industry expansion from 1950 on, following different patterns of integration at national scale, diversifying relations between borders and political centers and morphological differences on each system separately. Our objective in this paper is to describe road networks configurational differences for each South American country in order to depict their potential centralities and analyze changes emerging from regional subsets defined by cooperative projects. Our hypothesis is that national road networks centrality hierarchies are modified at regional scale, hence related to structural changes on cross continental accessibility and connectivity. The methods applied to depict South American road network structure combine data collected from national transport databanks gathered on a GIS platform where road centre lines were captured, revised, simplified and generalized. Following Space Syntax methods, national, regional and continental road
networks were modeled with *Depthmap x 0.5* appliance that enabled axial and angular multi-scale analysis of integration and choice measures. Analyses performed evidence changes on national goals towards endogenous and exogenous patterns of spatial integration. Results display road networks centrality hierarchies underlying cross-border flows probability at local scale, corroborating strategic shifts on regional integration patterns and cooperation policies along South America recent history.

**KEYWORDS**
MERCOSUR, South America territories, road network multi-scale configuration, cross border integration

**1. INTRODUCTION**

According to early 20th century geographers like Vallaux (1928), it is important to differentiate the notions of limits and territorial borderlines, since the last one incorporates the idea of frontier as a peripheral and dynamic device, subjected to the strength of neighboring national societies. Nowadays, cross-border flows recall these notions in, revising them under the spell of multidimensional integration and regional cooperation that detach economic frontiers from territorial limits, giving emergency to jurisdictional borderline zones issues in the political agenda.

Integration improvement between South America national states became urgent after the creation of MERCOSUR (1991) economic block in 1991. Despite their divergences towards integration expectations at local and national spheres, cross-border exchanges date back to colonial times, when economic and social relations at frontier zones subverted the ones imposed by European Colonial powers. This frontier zone context is most noticeable within the influence area of South America geographic core - the La Plata River Basin -, which encompasses 28% of actual national territories as follows: Paraguay100%, Uruguay 79%, Argentina 34%; Bolivia and Brazil +-17% (Vilella, 1984; OEA, 2005). Territorial disputes imposed peculiarities to its occupation process and the endurance of cross-border relations between neighboring countries at local scale (Braga et al. 2016).

The “regional approach” to long lasting frontier zone practices are based on cooperation projects that regulate robust historical cross border exchanges in order to improve their efficiency and contain their negative outcome, what is not exempt of conflicts, revealing the unevenness of power between transnational institutions’ members, where MERCOSUR founders and signatories of the 1st La Plata Basin Agreement (Brasilia, 1969) prevail over other national states. Unevenness in population size, economic dynamics and resources mediate planning strategies for which transnational and cross-border relations reorganize endogenous infrastructure networks, in order to accomplish shared goals towards South American commodities competitiveness improvement. In most cases, institutional and political interests orbit around transportation efficiency and economic and functional resources strengthening, while preserving national state territories’ cohesion (Bender, 20??).

A regional space is defined by sets of subspaces whose multidimensional and multiscale interactions grant discontinuities within discrete spatial systems, such as urban and road networks. Complex systems definition as “a set of elements related to each other, which interactions’ structure depict tendencies or bifurcations on the system self-organization” (Aschan-Legonye, 1999) address heterogeneity and as the main property informing spatial organization: “if geographical space is considered as a set of interacting elements, spatial structure must be understood as the organizing principle of the geographical entity under study, which is materialized under a form (axis, pole, etc)”. (Elissalde, 2004). Therefore, circulation networks continuity across territorial limits encompassing whole continents, change flows intensity and their direction, modifying urban networks hierarchies at regional scale, that update polarization processes and the recurrence of economic and functional activities at local scale.
Such problem requires multiscale analysis to depict phenomena related to spatial networks structuring logics rather than territorial ones. As appointed by Milton Santos (2006, p.188), “the expansion, superposition and integration of different networks at global scale are changing networks’ spatial limits, and modifying polarizations, therefore giving emergency to new territorial orderings”. From that we drew our objective, which is to describe and analyze the spatial configuration of each national urban network and their changes emerging from planning strategies imposed by transnational projects in South America that are informed by the opening of new markets (Asia+ Africa, 53% Brazil gross exports: Russo et al, 2007) for South American commodities, what modified cross-border flows (Wilmsmeyer; Sanchez, 2009). UNASUR (South American Nations Union, 2015) supranational projects target to improve complex interactions beyond state control, through strategic territorial planning tools managed by COSIPLAN (South American Council on Infrastructure and Planning) and IIRSA (Initiative for Integrating South America Regional Infrastructure, 2012). One of such tools draw from the notion of development corridors as “spatial cutoffs encompassing urban network main hubs and demographic or economic concentrations along a trading route” (Bender, 20??), to improve infrastructure systems connectivity at continental scale along project axes, the urban network’s nodes to their surrounding territory; and to promote multimodal integration through logistic hubs. Their targets are “to improve connections in networked spaces with different topological depths across national territories” (Fau et al, 2016), what tend to modify infrastructure networks topology, producing hierarchical changes in urban networks at continental scale (Figure 1).

The notion underlying this research problem and its analytical scale is that of urban networks as self-organizing systems, which structures are codependent to the circulation and transportation ones. Therefore, it is expected that if their continuity and connectivity patterns are modified through uneven fusion processes across territorial borders, then hierarchical changes will occur at regional scale, impacting borderline gateways that acquire new significance towards local and regional integration patterns.

Our hypothesis is that national road networks centrality hierarchies are modified at different scales, hence related to configuration changes imposed by cross continental accessibility on regional subsets or spaces. This approach attests the efficacy of Space Syntax methods and tools in providing a systemic analysis of multiscale change processes emerging from different
territorial framings imposed upon South America urban network, that relate to polarization processes at regional and national scales. The case study reiterates research findings conducted by Turner (2007), Serra et al. (2012) and Hanna et al. (2013), validating its appliance in regional studies.

2. DATASETS AND METHODS

According to PUMAIN (2004) a configuration underlies the production of every spatial organization. Spatial configuration analysis enables descriptions of multiscale changes in interactions between territorial planning goals at national scale, and new forms of spatial organization based on economic integration at regional scale, to depict the morphological variables enacting hierarchical changes within urban networks, and give emergency to complex phenomena at regional scale such as polarization and functional specialization.

SERRA et al. (2015) state that “a GIS network representation of road-centre-lines, when analyzed by space syntax topo-geometric centrality measures, could emulate the syntactic segment representation derived from axial lines”. Such network models enable the identification of qualitative and quantitative form-function asymmetries emerging from polarization processes, conceptualized as “the attraction exerted by one place over heterogeneous space, proportional to regional agglomerate development, described through different urban networks centrality measures” (Elissalde; Saint-Julien, 2004).

Road networks topo-geometric structures combined into different subsets depict multiscale relations and interchanges informing regional disparities and tendencies for hierarchical changes that enable to analyze spatial integration asymmetries between Brazil and its South American neighbors. If both are functions of multiscale centrality measures of circulation networks as pointed by Turner (2007), Hanna et al (2013) and Serra et al. (2014), testing limits for road networks is a methodological exercise that might unveil peculiarities related to these networks continuity across territorial borders, and depict subsets’ changes that modify local development tendencies.

The segment models put together to perform the proposed analysis were firstly based on road-centre lines, depicted from available GIS database (Open Street Map, 2014; IIRSA, 2016). This method proved itself problematic for the following reasons: a) network connectivity failures and incompleteness of road networks on the selected geographic scale (1:5.000.000) due to differences in geometry and density of each country road network and geographic constraints in territorial occupation patterns; b) differences in roads features categories that turned unviable the modeling of such graphs without imposing some generalization and simplification rules to the base that implied in a complementary segmentation process.

According to Jiang & Claramunt (2002, a/b) and Mackaness et al. (2007), linear objects (streets, roads) generalisation rules target to retain the network basic geometric, topological and semantic properties. It consists of data filtering and geometry simplification, in order to reduce the road network complexity, while retaining its spatial structure. Therefore, features and attributes of road categories were homogenized and grouped, complying with reduced scale parameters. Graphic generalisation consisted in simplifying geometric features, retaining the network spatial structure. The authors suggest that linear representation of generalisation procedures is a cartographic ordering process, which routines preserve the network main characteristics, being context dependent.

Procedures incorporate “perceptual grouping” to reduce the network detail level, preserving its connectivity, interdependencies and linkages with other contextual data such as political boundaries. Perceptual grouping is a phenomenon through which human visual system spontaneously depicts elements of visual fields and groups them according to their features, such as continuity. It enables to infer information on relations (Mackaness et al, 2007, p.260) and retain geometrical and structural detail -strokes-. In line simplification routines, it allows the removal of whole strokes, without compromising the network generic geometric properties. Therefore, segment length and connection type ("T" - representing dead end
country roads) were suppressed i diminishing irrelevant information and the network size in number of segments. Vector simplification consisted in fusing segments ≤ 2m in road turns segmentation. Therefore, semantic (road type) and geometric (segment length) data were simplified, resulting in a graph that preserved the network topology consistent with both, axial and segment maps, proposed by Space Syntax methodologies. As stated by Mackaness (*idem*) “the associate segment geometry could be represented by a *poliline* structure, weighted according to different properties, in order to obtain the network shortest paths, preserving its topological characteristics such as adjacency and connectivity”, providing a controlled generalization. The same simplification and generalization rules were applied on each national state transport authority map - either shape files or raster images (Chart 1) - to homogenize discrepant features - roads classes and geometric detailing, indispensable to perform angular analysis at continental scale. Routines applied: a) grouping of roads types into a single vector layer since national classifications met no equivalence among themselves; b) suppression of features (strokes) in order to minimize the number of segments in each subset; c) compose multiple geo-referenced assemblages of continental, national and regional subsets on the database. Geometric distortions were corrected applying *Rubbersheeting* (©ArcGIS 10.1 Pro; Arcmap) to adjust raster bases after converted to planar projection - WGS 1984 Web Mercator to regroup each national map into *Open Street Map* database, enabling the analyses on Depthmap x 0.5 (Varoudis, 2013) as seen in Figure 2.

<table>
<thead>
<tr>
<th>National State</th>
<th>Territorial area / km²</th>
<th>Terrestrial Borders/ km</th>
<th>Road network/ km</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>8,515,767,049</td>
<td>15,735</td>
<td>1,751,000</td>
<td>DNIT - Transport Infrastructure State Department - VGEOL Atlas multimodal <a href="http://www.dnit.gov.br/planejamento/dnit-geo">http://www.dnit.gov.br/planejamento/dnit-geo</a></td>
</tr>
<tr>
<td>Uruguay</td>
<td>176,215</td>
<td>1,564</td>
<td>30,331</td>
<td><a href="http://www.mtop.gub.uy/documents/20182/21207/mapasMapa+dnv.pdf/60b8cd22-430b-439f-a797-5686d59e76e3">http://www.mtop.gub.uy/documents/20182/21207/mapasMapa+dnv.pdf/60b8cd22-430b-439f-a797-5686d59e76e3</a></td>
</tr>
<tr>
<td>Bolivia</td>
<td>1,098,581</td>
<td>6,743</td>
<td>80,488</td>
<td>Estado Plurinacional de Bolivia ABC-Administradora Boliviana de Carreteras <a href="http://www.abc.gob.bo/mapas-de-la-red-vial-fundamental">http://www.abc.gob.bo/mapas-de-la-red-vial-fundamental</a></td>
</tr>
</tbody>
</table>

Table 1: South America national states information and road maps and databases

1 Complementary information sources in Table 1:
[http://www.ibge.gov.br/home/geociencias/cartografia/default_territ_area.shtm](http://www.ibge.gov.br/home/geociencias/cartografia/default_territ_area.shtm);
Combining different simplification and generalisation methods allowed us to depict the network model topo-geometric structure at a) continental scale; b) national scale; c) regional scale: subsets / transnational development projects framings into 6 subsets (Chart2).

<table>
<thead>
<tr>
<th>Subset</th>
<th>NATIONAL STATES</th>
<th>BOUNDARIES LIMITS</th>
<th>JUSTIFICATION</th>
<th>GROUPING CRITERIA</th>
<th>PLANNING UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subset 1</td>
<td>Argentina, Brazil, Bolivia, Chile, Paraguay, Peru</td>
<td>Brazilian (N) Amazonia borderline</td>
<td>Road connections inexistent / precarious</td>
<td>Contiguity; cross-border continuity</td>
<td>National States territories</td>
</tr>
<tr>
<td>Subset 2</td>
<td>Argentina, Brazil, Chile, Paraguay, Uruguay</td>
<td>National territories</td>
<td>Shared borderlines</td>
<td>Contiguity</td>
<td>Brazilian Frontier Strip South Arc</td>
</tr>
<tr>
<td>Subset 3</td>
<td>Brazil, Bolivia, Paraguay, Peru</td>
<td>National territories</td>
<td>Shared borderlines</td>
<td>Contiguity</td>
<td>Brazilian Frontier Strip Central Arch</td>
</tr>
<tr>
<td>Subset 4</td>
<td>Brazil, Argentina, Chile, Paraguay, Uruguay</td>
<td>From Belo Horizonte (BR) to Santiago (CH)</td>
<td>Territorial planning: development axes</td>
<td>Interaction potential</td>
<td>MERCOSUR-Chile Axis (IIRSA, 2012)</td>
</tr>
<tr>
<td>Subset 5</td>
<td>Argentina, Brazil, Paraguay, Bolivia, Peru</td>
<td>From Rio de Janeiro (BR) to Lima (PE)</td>
<td>Territorial planning: development axes</td>
<td>Interaction potential</td>
<td>Trans-Oceanic Axis (IIRSA, 2012)</td>
</tr>
</tbody>
</table>

Table 2 - South America road networks models subsets
The multiscale urban network analyses were based on cities relative position within South American road network. Space Syntax modeling methods (Al-Sayed et al., 2013) were tested on a pilot study (Braga et al., 2016) enlarged on this ongoing research. To verify the hypothesis, axial and segment modeling were performed with Depthmap x 0.5 (Varoudis, 2013; Hanna et al., 2013). Axial and angular analysis performed for each subset at global and local topological radius intend to verify the efficiency in establishing territorial decoupages to improve network connectivity. The following axial and angular measures were modeled:

a) Global Integration (HH-Rn, Int): closeness centrality nodes’s adjacency or relative accessibility to infer origin - destination movement potentials within subset networks at global (n) and local radius (R50 and R80) in order to evaluate the degree of integration / segregation of urban networks in each national territory and spatial decoupages;

b) Choice: betweenness centrality (bridge effect on flows probability) computes a node’s frequency in every possible path used to reach other nodes in the network, displaying the shortest paths from all origins to all destinations and forecasting traffic flows ((Hillier et al., 2007 & Hanna et al., 2013); was applied to evaluate borderline gateways hierarchical position towards cross-border and transnational flows probability.

3. DISCUSSION AND RESULTS

The discussion is based on the modeling of subsets displayed in Chart 2, which measurements provide the basis for qualitative comparisons as follows. The analysis of Subset 2, comprising the continental and each national road network (Figures 3, 4) unveils differences on Portuguese and Spanish colonization processes and the integration structure underlying modern national states territorial configuration. Global integration axial measure (HH-Rn) informs that road networks are sparse, tending to spread from main seaports dating back to colonial times, linking capital cities to the territory - Uruguay, Chile and Peru -. Their syntactic centres configurations validate the polarization processes where functions and population are concentrated in a single metropolitan area, contrasting with the inland sparse urban network.

Locked out countries (Wilmsmeyer; Sanchez, 2009) - Paraguay and Bolivia - which national territories were defined from disputes over the La Plata Basin in late 19th century, display their road networks spreading from their geographic cores. Endogenous territorial integration is modified by the polarization exerted by terrestrial borderland with Brazil (E) that directs the syntactic centre to gateways such as the triplet-cities Ciudad del Este (PA)- Foz do Iguaçú (BR) and Iguassú (AR) and the connection Campo Grande (BR)- Santa Cruz de la Sierra (BO).

Brazil road and urban networks are denser and more evenly distributed connecting a larger number of small and medium size towns, therefore displaying different polarizations at global and local scales. Strategies to occupy the territory dating back to 1960ies included a new capital - Brasília (1960) - in its geographic centre - what improved the urban network density inland and stretched the road network syntactic centre from São Paulo, Belo Horizonte and Rio de Janeiro (SE), towards Northeast and West regions.

A common feature to every country depicted in this sample is the presence of large areas where the network is scarcely connected, contrasting with their density around capital cities, both at global and local scale. Brazil is the exception, where integration is more evenly distributed. At local scale (HHR50) axial integration depicts the earlier occupied and explored regions (North East, South East and South) cores. The most segregated areas are Amazonia (rain forest), Pantanal (wet planes) where road network connections are scarce.

Apart from Peru, where differences between global and local integration depicts the area between Potosi (next to Bolivia borderline) and Lima, the actual Pacific coast city, global and local syntactic centres are equivalent; and Argentina where the polarization exerted by Buenos Aires (population share and functional concentration) does not correspond its territory syntactic centre which spreads from Baia Blanca - Rosario - Cordoba - Salta axes. Chile and Argentina road networks connections are affected by the Andes ridge barrier and the Patagonia discontinuous territory what insulates road networks in its southern stretch.
Highest integration measures are generally low (Chart 3), best results achieved for most compact and bigger (in number of lines) road networks such as Brazil and Argentina (Chart 3). Chile lowest integration measure is tributary to its linear territorial shape and topographic barriers, that impact the road system, composed mainly of dead end roads linking segregated towns. Highest and mean global integration measures tend to be discrepant, since road network configurations concentrate integration along few lines, usually short range ones, spreading from Capital cities. That informs, at national territories scale, that large parts of inland territories are segregated a phenomenon intertwined with that of metropolisation, which is common to most South American countries.

This phenomenon is characterized by concentration of functions and population in single intensely urbanized areas (Capital cities) which configurational centrality prevails over sparse and weak urban networks, which exceptions are Brazil and Argentina. In the first case, Brazil morphological centrality is pushed North, under the influence of Brasilia which act as the main crossroad to territorial connections. As for Argentina, the same phenomenon occurs regarding Cordoba and Rosario that distribute integration along the axis linking Baia Blanca Port to Argentina northern borderland.

When it comes to local (or regional integration) modeled at radius 50, which was the one radius that depicted scale changes for most of national road systems, it depicted subspaces that inform endogenous territorial subsets as in Brazil (North / Centre-West) more segregated and sparsely occupied areas, South, Southeast and Northeast regions which morphological cores tend to be detached from capital cities, driven inland by the force of a national road (BR116). Other integration measures at local radius were modeled, but by force of homogenizing data, are not displayed here. Coincidence between global and local integration measures can be verified through synergy correlation (Rn x R50) displayed in Chart 3.

![Maps showing integration measures](image-url)

Figure 3 - Subset 2 - Axial global (HHRn) and local (HHR50) integration measures (FAURI, 2016).
## Table 3 - Axial measures and synergy correlation for each national state road network

<table>
<thead>
<tr>
<th>National states ROAD SYSTEM</th>
<th>Number of axial lines</th>
<th>AXIAL INTEGRATION GLOBAL HHRn</th>
<th>AXIAL INTEGRATION LOCAL HHR50</th>
<th>SINERGY RnxR50 (R²)</th>
<th>AXIAL CHOICE (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARGENTINA</td>
<td>1557</td>
<td>0.1888</td>
<td>0.1385</td>
<td>0.2998</td>
<td>0.661</td>
</tr>
<tr>
<td>BOLIVIA</td>
<td>600</td>
<td>0.1173</td>
<td>0.1010</td>
<td>0.2337</td>
<td>0.734</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>4964</td>
<td>0.1973</td>
<td>0.1278</td>
<td>0.3179</td>
<td>0.325</td>
</tr>
<tr>
<td>CHILE</td>
<td>1180</td>
<td>0.0703</td>
<td>0.023</td>
<td>0.2619</td>
<td>0.3048</td>
</tr>
<tr>
<td>PARAGUAY</td>
<td>525</td>
<td>0.2731</td>
<td>0.2198</td>
<td>0.2812</td>
<td>0.9769</td>
</tr>
<tr>
<td>URUGUAY</td>
<td>612</td>
<td>0.3440</td>
<td>0.2747</td>
<td>0.3440</td>
<td>0.97</td>
</tr>
</tbody>
</table>

PLURAL TERRITORIAL INTEGRATION AND ROAD NETWORK CONFIGURATION IN SOUTH AMERICA
From Figure 5 it is possible to attest that routes crossing the continent with highest flow probabilities spread from Brazil SE region, where São Paulo, Rio de Janeiro and Belo Horizonte metropolitan regions tend to form a dense and highly connected road network depicted by Angular Choice Global measure (network / subset 1).
Figure 5 - Global / Local (R80) Angular Choice: Subsets 1 (above), 2 (centre) and 3 (below). Fauri, 2016.
This polarization tendency at continental scale is confirmed through Angular Choice for Subsets 2, 3 (Figure 5) at global scale, where the measure captures higher flow probabilities spreading from Brazil SE towards main cross-border gateways (SW - NW). The measure validates the functional polarization exerted by these three main production hubs distant 500km from each other, as the core of South America road system. These findings attest for the strength of La Plata River Basin in structuring the continental inland urban network and the relevance of road networks continuity across territorial limits. Transnational and cross-border flow probabilities inform twin-cities located along Brazil Southwestern borderline functional specialization, phenomena related to morphological and topo-geometrical properties of road networks.

Angular Choice at radius R80 depicts routes linking São Paulo to Pacific cargo seaports in Chile and Peru, that equals IIRSA development axes MERCOSUR-Chile and InterOceanic. Subset 2 Uruguaiana (BR) is depicted as the borderline gateway with highest flow probability, and Mendoza (AR), the main Andes crossing between Argentina and Chile. Subset 3, the route segment between Campo Grande (BR) and Cochabamba (BO), has the highest flow probability connecting Brazil (W) and Bolivia to Peruvian ports.

For instance, through Uruguaiana (BR) (Figure 6), encompassed by 3 development axes (IIRSA, 2012), cross-border transit reaches 700 trucks per day. This town, distant more than 1000km from São Paulo, has the biggest South American logistic hub in commodities volume. At this gateway, cargo flows towards Argentina are 5 times higher than from there to Brazil. Hence the spatial logic underlying changes in functional specialization phenomena within urban networks nodes reinforces the importance of cross-border flows at the continental scale, targeted by transnational territorial planning strategies.

Transnational integration goals for urban network subsets economic development relay on flow probability across regional space as in MERCOSUR-Chile Development Axis (IIRSA, 2012). Despite efforts to minimize flow unevenness through cross-border gateways and, by doing so,
improve cargo transportation time, the topo-geometric network proprieties prevail in selecting the main gateways (cross-border bridge effect) along territorial borders, where logistic hubs are located. These effects are enhanced by infrastructure investments and cooperation projects, which firstly targeted to channel cargo cross-border flows through few surveillance gateways - as the International Bridge at Uruguaiana - Paso de los Libres (BR-AR binational project, 1945) and, nowadays, the focus is to provide infrastructure to segment cross-border cargo flows in order to diminish cargo transport time.

Busy cross-border gateways such as Foz do Iguaçú (BR) and Uruguaiana (BR) are highlighted at global scale choice measure, what confirms their roles as logistic and commercial hubs on the La Plata River influence area. They attest for regional integration resilience that differentiates exchanges and interactions, informing cultural hybridization and cross-border economic and functional complementarities within the urban network what, at local scale, give emergency to gateways functional specialization phenomena. Integration limits a region encompassing the whole Southeast Brazil, sprawling southwards.

Analyzing Axial Integration measure at global (HHRn) and local (HHR50) radius it becomes clear that at global scale, that the syntactic core of South America coincides with the La Plata Basin influence area, which has been disputed by Brazil and Argentina for long and that gave emergency to Uruguay and Paraguay national states. At local scale, the syntactic core of South America remains in Brazil, this time depicting the area between Brasilia and São Paulo tending to sprawl towards West, encompassing Paraguay, Bolivia and Northern Argentina territories a frontier region that depict the influence Brazilian urban network exerts over its neighboring national state. (Figure 7). It is important to stress that network centrality measures such as angular choice, modeled at different scales and spatial limits, depict flow probability providing preliminary evidences informing cross-border gateways functional specialization phenomena. Multivariate analysis encompassing other dimensions of the phenomena, might validate or change such tendencies, specially local scale analysis (Campos; Braga; Lucca, 2017).

Figure 7 - Axial Integration at global (HHRn) and Local radius (HHR50), highlighting the MERCOSUR-Chile Development Axes (IIRSA, 2012) spatial limits. Fauri, Braga, 2016.
4. CONCLUSIONS: MAPPING THE STRUCTURE OF CONTINENTAL CHANGES

This paper presents preliminary findings on South America road and urban networks interactions that indicate the morphological variables informing cross-border gateways functional specialization and polarization processes within urban network regional subsets. The main target in this stage of research was to overcome the methodological problems refereeing to the size of the continental road network; asymmetries and classification differences between national road networks and distortions in the geographical shape of national territories in planar projections.

Focusing on a qualitative approach to the problem, which limits were established by lack of homogeneous methodological parameters for statistical data to each national territory, as well as automation of simplification and generalisation routines to represent the network model, we draw few conclusions from the analysis performed. From these, we highlight the fact that researches insights that different network decoupage methods modified national road networks centrality hierarchies at different scales, hence related to configuration changes imposed by cross continental accessibility on regional subsets or spaces was validated.

Integration measure axial modeling provided sufficient evidence to discuss the problem, since the analysis focused mainly network topology at this research stage. Topological and topo-geometric analysis reiterated the integration cores and route choice systems across the continent. Specifically, different subsets confirm the dominance of Brazilian road network over the whole continent related to the network geometry, compacity and connectivity, capturing flow probability within its territorial limits; what enhances unevenness in the relations with neighboring countries and regional block partners.

Restrictions for road network connections to the North and Northwest are presented by Amazonian rain forest, that spreads from Brazilian Atlantic coast to Peruvian Pacific one as well as Andes ridge which barriers draw blanks on the road network circulation system. Most CSIPLAN - IIRSA projects (2015;2016) incorporate other transport modals and development axes investments target to improve connectivity between transport systems. Since July 2016 COSIPLAN-IIRSA (2016) publish an on-line / open access GIS platform from which we expect to obtain the cartographic data that enables syntactic analysis performed on an accurate road center line database. Nevertheless, scale problems persist and the development of decoupage and generalization methods are still the main problem we expect to face.

The hypothesis formulated here - that national road networks centralities hierarchies are modified at different scales and different spatial limits, hence related to configuration changes imposed by cross continental accessibility and connectivity on regional subsets or spaces, was validated by evidences obtained through axial analysis. The continental urban network core lays in the same La Plata River Basin area of influence, along Brazil SW Borderline Strip, proving the resilience of this frontier, understood as a development and expansion area. What changed in the past hundred years is that national states power games changed from sovereignty pretenses to leadership ones.

The continental road network configurational properties depict polarizing tendencies and inform national and regional urban networks centrality hierarchies in which South American important metropolis like Buenos Aires, Santiago do Chile, Montevideo and Lima remain segregated from its morphological centre. We recall Milton Santos (2006, p.188) to illustrate his statement on the reshaping of territories. For that, we display Subsets 4 and 5 MERCOSUR-Chile and Trans-Oceanic Development Axes modeling (Figure 8). From this, it is possible to note the expansion of cross border spaces spreading from Brazilian productive poles to Pacific seaports through which transnational cargo flows are reshaping territories and effectively changing the urban networks’ spatial limits, what gives emergency to new territorial orderings. These are enhanced through cooperation projects and incorporated into transnational planning tools, which agency is not exempt of domination, exerted by MERCOSUR founding members over South America continent.
ACKNOWLEDGEMENTS

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ABSTRACT
Since the start of industrialization the region joining Nuremberg and Fürth has been the site of drastic urban transformation. Germany’s first railroad was built there in 1835. During the post-1945 era, firms such as AEG and Quelle built large plants in the area. Yet by the beginning of the twenty-first century, the region’s industrial chapter had come to a close. Today, in the place where AEG and Quelle once stood are vast tracts populated by massive vacant buildings, some designated historic landmarks. For years now, officials have been in search of a feasible urban renewal plan for these abandoned industrial areas. One scenario under consideration is the erection of a regional university and research center on the former AEG factory grounds.

This paper investigates the opportunities and risks of urban development in the region against the backdrop of its postindustrial change. It examines the historical developments since industrialization by creating axial maps for different periods. This analysis shows that three cordons leave a powerful mark on the region, raising questions about how to traverse and link the districts they separate. The main connecting axis between Nuremberg and Fürth, Fürther Straße, has global importance in the regional network but is not locally significant. And without links to the surrounding areas, the street cannot urbanize neighboring districts. Further isolating the neighboring districts are stretches of large-scale building and development. Given these structural realities, the planned university center stands to become a space without urbanity, unable to advance the development of neighboring districts.

This case makes clear that the midpoint of direct connection linking the two urban centers cannot itself become a new urban center without enormous effort. The permanence and scale of the peripheral structures located there represent long-term obstacles to the formation of a new local center.

KEYWORDS
Space syntax, Urbanization, City Centres, Nuremberg, Fürth, Angular Segment Analysis
1. MOTIVATION

Post-industrial structural change in region joining Nuremberg and Fürth has raised an urban development scenario that has been considered again and again: the merging of both towns along the axis linking them. Though this endeavor has failed many times in the past and is currently no longer being seriously discussed by policymakers plans have been introduced to establish a new regional university and research campus in the area. These plans contain a vision already described in 1922: the creation of a new center, midway between the towns (figure 1). But the creation of a new regional university and the merging of the cities face structural obstacles to a new urban center between Nuremberg and Fürth. The main road connecting the cities – the former Nuremberg-Fürther Chaussee, which today is known as Fürther Straße in Nuremberg and Nürnberger Straße in Fürth – is an about six-kilometer straight line. The area in between seems better suited for driving by than for the construction of a new center.

This article examines and tries to understand the historical development of this connecting axis. It uses a space syntax approach to analyze the local and global importance of the area between Nuremberg and Fürth in historic and present state. On the basis of its findings, it then sheds light on the obstacles and oppositions that can arise the attempting to merge urban centers.

![Figure 1 - Poster (1922) for referendum that envisions a combined municipality in which Fürth is no mere suburb but an equal partner linked to a new commercial center and traffic hub between the two towns.](image.png)

2. METHODS

Axial line maps of the Nuremberg and Fürth region were prepared using information from three different years and sources: the Bavarian Lang Registry from 1850; a 1929 map from the Bavarian Topographical Office of 1929; and the 2015/16 issue of the Land Survey Register of the Bavaria Atlas (figure 1, top). For each map, the longest lines of sight among pedestrian-accessible streets were drawn by hand as vector graphics. Expressways and streets closed to pedestrians were not recorded.
The historical maps were chosen based on their ability to give insight into city growth during industrialization. Maps of Nuremberg and Fürth were also selected for their uniformity: a decision was made not to merge individual regional maps from different years. Unfortunately, for the period prior to 1800, no sufficiently detailed maps are available that show the road network before the construction of the Nuremberg-Fürther Chaussee (1801–1806). In an attempt to recreate this network, we used the land register of 1850 and removed all streets that could be plausibly assumed not to exist before the construction of the Nuremberg-Fürther Chaussee. The map dated 1800 is thus a reconstruction to gauge the changes that the Nuremberg-Fürther Chaussee effected on the road network.

The resulting four maps were analyzed using Depthmap X. Choice as a measure of ‘betweenness centrality’ and Integration values as a measure of ‘closeness centrality’ were calculated for various radii using angular segment analysis. These topo-geometric syntactic analyses of the street network are accompanied by a historical examination of the region’s urban morphology and use structure.

Figure 2 - Top: Bavarian Land Register, 1850. Middle: Map of the Bavarian Topographical Office, 1929. Bottom: Aerial photograph, Bavaria Atlas, 2017.
3. HISTORY

The first written mentions of Nuremberg and Fürth came soon after the start of the second millennium. During the Middle Ages, Nuremberg first rose to prominence as a free imperial city of the Holy Roman Empire. Its importance overshadowed that of Fürth, which was subject to changing rule – first under the Principality of Ansbach and later under the provost of Bamberg and the Imperial City of Nuremberg. Fürth did not receive a town charter until 1806, when Emperor Francis II dissolved the Holy Roman Empire of the German Nation and the Kingdom of Bavaria annexed Nuremberg with the support of the French army. Today, Nuremberg and Fürth have around 500,000 and 200,000 inhabitants, respectively. In the German classification system, this makes them Großstädte, towns whose population exceed 100,000.

Construction on the first modern, direct route between Nuremberg and Fürth south of the Pegnitz River began in 1801 at the behest of Karl August von Hardenberg, a Prussian state official who administered the Ansbach-Bayreuth region for the Prussian crown, and was completed in 1805. Before that, travelers had to use a country lane that meandered on the north side of the Pegnitz River through Nuremberg’s New Gate, St. Johannis, and Schniegling (figure 3). At Doos, a bridge over the Pegnitz finally brought them to a series of winding paths leading to Fürth. The significantly faster new road, known as the Nuremberg-Fürther Chaussee, followed a straight line that cut through unpopulated parcels of land south of the river – obviating the need for river crossings – and curved slightly before reaching Fürth. Unlike the previous route, which extended radially from the New Gate, the chaussee was tangent to the city’s ring-like wall beginning at Plärrer, a square located just outside Ludwig’s Gate where medieval farmers and merchants freely plied their wares. Though the chaussee reduced travel time between Fürth and Nuremberg, it did not extend into either of the town’s medieval centers.

Figure 3 - Left: Roads leading from Nuremberg before the construction of the Nuremberg-Fürther Chaussee (Höhn, p. 47). Right: map of the railway along the Nuremberg-Fürther Chaussee, 1836 (Deutsche Bahn Museum, Nuremberg).

The Nuremberg-Fürther Chaussee was the longest transport axis in the region. Choice analysis indicates that the new road considerably weakened the significance of the old route as a connection (figure 7; log choice radius n). In 1800, Plärrer Market was the most globally integrated place in Nuremberg and the surrounding area; the globally preferred paths were the routes around the ring wall. The new chaussee shifts importance to the southern paths around Nuremberg’s ring wall and weakens the north-western routes around the ring wall. In Fürth it emphasizes the eastern part of town and weakens the significance of the bridge across Pegnitz in the north east (figures 3,7,8).

1 In building the road, the Prussian administration sought to circumvent the tolls levied by Nuremberg on existing routes. See Centrum (1985), p. 8
2 In all likelihood, a rural route leading to Fürth through Muggenhof existed south of the Pegnitz, but its exact path remains unknown. See Centrum 1986, p. 8 ff.
3 Today Pegnitz is called Ludwigsbrücke.
At the same time, the area between Fürth and Nuremberg south of river Pegnitz remained unimportant: locally, at a radius of 800 meters, no new subcenters along the new road are detectable. Highlighted areas of small ‘urban seeds’ at a radius of 800 meters (see Hillier, 2009) continue to occur north of the Pegnitz, in Schniegling and Wetzendorf in 1850 (log choice, integration; figures 7,8).

4. TRANSPORT ROUTES AND INFRASTRUCTURE CORRIDORS

In 1835, construction began on Germany’s first railroad, the Bavarian Ludwig Railway. The line ran alongside the wide corridor of the Nuremberg-Fürther Chaussee and terminated in Fürth. In 1844, the Ludwig Railway received its first connection station. Located between Doos and Muggenhof, the Fürth Junction intersected with the northern stretch of what would soon become the Ludwig South-North Railway running from Lindau to Hof. The Ludwig South-North Railway sparked the construction of a central station in Nuremberg (1847) and in Fürth (1865). Running along the southern side the new chaussee, the corridor for intercity train traffic interrupted the only major lateral connection south of Fürth between Doos and Dambach. Another development at this time was the construction of the Ludwig Canal. Dedicated in 1846, it was designed to transport goods from the Main River in Bamberg with the Donau River in Kehlheim. The canal ran south of the Ludwig South-North Railway and at Doos crossed the Nuremberg-Fürther Chaussee and the Pegnitz. Economically, the canal was unable to compete with the rapid expansion of the region’s railway lines and flopped. Starting in 1881, the traffic and transportation network in Nuremberg and Fürth underwent further expansion. A private horse tramway was built between Plärrer square and the more centrally located Fürth fruit market, parallel to the Ludwig Railway. The tramway was electrified and placed under municipal authority at the turn of the century. No match for the direct competition, the Ludwig Railway discontinued service in 1922. Germany’s first railway was replaced not by a modern long-distance train but by a tram4.

The region joining Nuremberg and Fürth soon saw more drastic changes to its infrastructure. Shipping on the Ludwig Canal ceased after Hermann Jansen introduced his master plan for the region (1921–1932), which foresaw the construction of an expressway alongside the railway to replace the canal – an idea later endorsed by the National Socialists. But a road was not built on the canal corridor until the 1960s. The Frankenschnellweg (“Franconia expressway”) began as a thoroughfare and later became a controlled-access highway. Then, in 1972, the electric tram line was replaced by the U1 subway. This subway line, following the old chaussee, eventually had five stops between Nuremberg and Fürth, and was elevated starting at Eberhardshof. The construction of the subway altered the appearance of Fürther Straße, changing its width and course multiple times. In some sections, the road runs north of the subway line; in other cases, south. Now the road sometimes has four lanes with a median and sometimes two lanes with wide sidewalks. Thanks to the subway and the Frankenschnellweg, travel between the towns became faster. But the corridor also created a significant barrier between the neighboring quarters along the north-south axis.

5. MERGING NUREMBERG AND FÜRTH

The construction of the Bavarian Ludwig Railway introduced the idea of merging Nuremberg and Fürth into a single municipality. After several failed political initiatives in the nineteenth century, a referendum was held in 1922. It failed with a vote of 64.8% against. Later efforts by Nuremberg’s National Socialist mayor Willy Liebel to push through a merger without a vote did not succeed. After the war, several new attempts were initiated but failed as well, mostly on account of the strong reservations each town held about its neighbor. On October 3, 1990, the Green Party organized an ironic event at the boundary of Nuremberg and Fürth. Under the banner of “Now what has always been side by side will grow together” the party celebrated the towns’ “unification,” renaming Nuremberg as “East Fürth.”

October 3, 1990 was also the day of German reunification. The slogan played on Willy Brandt’s much-cited 1989 quote in response to the fall of the Berlin Wall: “Now what belongs together will grow together.”
To date, Nuremberg and Fürth have been unable to form a shared urban identity; on the contrary. The residents are deeply attached to their respective historic center and define themselves in contradistinction to their neighbors. Neither side is committed to forging a shared center and a common identity.

6. LOT SCALE AND LAND USE

In 1850, the area between Nuremberg and Fürth was for the most part undeveloped. In later years, it grew into one of the most important industrial zones, with companies such as Siemens-Schuckert, Hercules, Triumph, and Mars setting up headquarters there. Industry continued to bloom until the 1970s, when gradual postindustrial change began, bringing fundamental transformation to the region. A prime example is the former AEG industrial grounds. Starting in 1914, it was the site of the Bing Works, a manufacturer of tin toys and domestic goods. In 1921, Bing merged with AEG, a Berlin firm founded by Emil Rathenau. AEG began producing ovens and heating units at its Nuremberg plant in the 1930s; during the war, it manufactured arms with the help of forced labor. In the post-war era, AEG reemerged on the wave of the German economic miracle, and the Nuremberg plant was retrofitted for washing machine production. In the 1980s, the domestic manufacture of appliances was hit by a crisis and AEG, after filing for bankruptcy, was acquired by Daimler Benz. In 1994, the domestic appliances division was absorbed by Electrolux. The last Elektrolux washing machine rolled off the lines in 2007, when domestic production was relocated to Poland. A project developer subsequently bought the former AEG factory grounds as rental space. Today, large parts are still vacant, though the Elektrolux administration remains headquartered there and around 6,000 square meters are currently occupied by Energy Campus, a research association of regional universities and research institutes founded in 2011. The Energy Campus is currently being considered as the starting point for further university expansion at the site.

Starting in 1955, the mail order company Quelle, founded in 1927 by Gustav Schickedanz in Fürth, erected a modern multi-floor industrial building with a clinker façade and ribbon windows on Fürther Straße. Despite the company’s success in the post-war era, it declined amid emerging online commerce and in 2009 filed for bankruptcy. The former Quelle building, designed by the German architect Ernst Neufert, comprises 250,000 square meters spread out over just under seven hectares, and is currently the largest vacant building in Germany after the Tempelhof Airport in Berlin. In 2015, the Quelle building was sold in a forced auction to a Portuguese investor for a mere 16.8 million euros. Though the development plan is still uncertain, the structure will likely be preserved given its status as a historic landmark. That being said, it nevertheless interrupts the development zone between Fürther Straße and the Frankenschnellweg, creating a permanent obstacle to stronger links between the neighboring areas to the east and west. Both the AEG and Quelle areas have proven difficult to redevelop due to the size of the buildings (some designated landmarks) and the industrial scale of the lots.

Two other structures between Nuremberg and Fürth bear mentioning. The first is a fenced correctional facility, built in 1865, located on an eight-hectare site north of Fürther Straße. Right next door is the Palace of Justice, a large urban structure on Fürther Straße completed in 1916 (and the site of the Nuremberg trials). Like Quelle and AEG, the expansive complex of buildings that make up the prison and the courthouse form a barrier to urban development. In particular, they further corset Nuremberg’s Bärenschanze district between Fürther Straße and the river, isolating it from surrounding neighborhoods. The industrial development along Fürther Straße and its peripheries that started 150 years ago still today blocks small-scale urban and residential development in the area.
7. A TRIPLE CORDON AND A SHARED BOUNDARY

Three structural cordons bound the area between Nuremberg and Fürth: the Pegnitz River to the north, Fürther Straße in the middle, and the Frankenschnellweg to the south (figure 7). Each cordon creates linkages along the northwest-southeast axis but creates barriers along the transverse axis. The Frankenschnellweg, together with the train tracks alongside it, can be crossed only four times in Nuremberg before the city limits at Muggenhof. And one of the crossings, the Leibsteg, consists of a small pedestrian path that runs along a community garden. Fürther Straße is no better. Forty meters wide, four lanes across at times, divided by a median in parts, and with a kilometer-long impassable stretch of aboveground subway line, long sections of the street lack crossing points connecting its opposite sides. Though some streets enter on one side, they frequently do not continue to the other. This is especially pronounced over the 2.5-kilometer-long section between Schumannstraße in Nuremberg and Finkenstraße in Fürth. What is more, the Pegnitz and its adjoining meadows close off large swaths of territory to the north. Here, too, there’s a dearth of routes linking districts on either side of the river. And at the edge of the river’s meadows are large structures that form an enduring barrier to neighboring districts: the Westfriedhof (West Cemetery), the correctional facility mentioned above, two wastewater treatment plants in Muggenhof (one built in 1913, the other in 1929), a community gardens, and several large commercial buildings. These structures prevent an urban network from forming between the northern and southern sections of the Pegnitz meadows.

Together, these structural cordons shape development at the border shared by the two towns. Peripheral and marginal structures dominate without a hint of shared urban development. There are (on the Nuremberg side) large commercial buildings, the aforementioned AEG complex, a water treatment plant, the partly abandoned tramcar depot in Muggenhof (now an historical landmark), and (on the Fürth side) a public utility company, today infra fürth gmbh. Until fairly recently, large-scale commercial development took place at the city limits, including the construction of furniture warehouses and car dealerships. And current zoning plans provide for continued commercial development around the former AEG factory grounds and between Frankenschnellweg and Kurgartenstraße. These conditions would even seem to be anchored in collective consciousness: the first subway station on the Fürth side bears the appropriate name ‘Stadtgrenze’ (‘city limits’).

Another key feature of the border area between the towns is the number of thoroughfares. The Frankenschnellweg crosses Fürther Straße with a wide expressway exit at the cross section. Furthermore, the Frankenschnellweg, together with the historical railway to the west and the Pegnitz River, cuts off Muggenhof from most of the surrounding area, rendering it an urban island. The only north-south connection, Adolf-Braun-Straße, links Muggenhof to the northern
part of Schniegling, but beyond the Frankenschnellweg it leads (as Sigismundstraße) to a large commercial area. The street, in other words, connects one commercial zone with another instead of linking mixed-use residential areas. Absent from the boundary of Nuremberg and Fürth are any early signs of a shared urban center.

8. THE GLOBAL AND LOCAL IMPORTANCE OF FÜRTER STRASSE

Today, Fürther Straße is the most important global connection with the highest Choice values for radius n (Choice) in the area under investigation. Locally, it is unimportant as a connecting axis up to a radius of 5,000 meters. It is a preferred path connection only starting at a catchment radius of 8,000 meters (figure 9, choice radius 500-n). Integration values also increase beyond a radius of 5,000 meters. The elevated values for Integration and Choice are located at the intersection of Fürther Straße with the four-lane ring road Maximiliansstraße. This is a major intersection in the foreground road network and is especially important for vehicle traffic.

The area surrounding Fürther Straße within the three cordons mentioned above shows no additional local path connections up to a radius of 5,000 meters. Only outside this sphere does another street – the Adam-Klein-Straße, which ends at the former Quelle building – gain importance. Moreover, at a radius of 5,000 meters, side streets leading to subway station at Fürther Straße over large intervals seem to be the preferred routes. Only the Eberhardsstraße station lacks such an important side connection. Both choice and integration values support the hypothesis that the region joining Nuremberg and Fürth is globally important, though it lacks a strong local center.

The comparison of catchment radii (figures 9, 10) shows that, as Nuremberg’s medieval center loses importance and the radius increases, Fürther Straße becomes more important. Today the center is still the most central part of the region in terms of closeness and betweenness-centrality up to a radius of 2000 m (figures 9,10). But it quickly loses importance at larger radii. It becomes important again exactly opposite to Fürther Straße at a catchment radius of 2000 m. This shows that Fürther Straße and its surrounding areas are creating local, urban centrality for pedestrians and a global centrality for motorized traffic. The centrality of Fürther Straße and the city center are not alike but they are complementary (figures 9, 10). If the foreground network of preferred routes (figure 9; choice at higher radii) is seen as a “deformed wheel” (Hillier 1996), today’s Fürther Straße is the straightest and longest spoke in the system. It resembles a spoke tangentially attached to a hub, the latter of which is represented by Nuremberg’s walled medieval core.

Also of note are the changes that took place between 1929 and 2016. Over eighty odd years the street network has become significantly denser outside the historic centers, but a similar density cannot be found along Fürther Straße. Here, especially in Muggenhof, around the former AEG and Quelle factories, and at the Palace of Justice, the urban grid continues to be large-meshed and gap-ridden. Corridors, buildings, and land zoning have prevented the grid from becoming denser. Paradoxically, the future-looking planning measures of the past predestined the area for a low density of street networks punctuated by peripheral structures. The rail, canal, and highways, the wastewater treatment plants, the factories, and the Palace of Justice complex stand in the way of “grid intensification” (Hillier 1999).
Figure 7 - Angular Segment Analysis Log Choice 1800, 1850, 1925, 2016, radii n and 800.
Figure 8 - Angular Segment Analysis Log Choice 1800, 1850, 1920, 2016, radii n and 800.
Figure 9 - Angular Segment Analysis Choice 2016, radii [m], 500, 800, 1,000, 2,000, 5,000, 8,000, 10,000, n
Figure 10 - Angular Segment Analysis Integration 2016, radii [m], 500, 800, 1,000, 2,000, 5,000, 8,000, 10,000, n
9. CONCLUSION

Neither in the medium nor in the long term is it likely that Nuremberg and Fürth will grow into a common mixed-use urban area, even if the mental and administrative hurdles are overcome. It is therefore likely that a new university campus on the former AEG factory grounds will assume a peripheral character. The urban barriers created by the wastewater treatment plants, the Pegnitz River, and an aboveground subway along Fürther Straße will prevent new university buildings from reviving neighboring districts. The campus project is mostly likely to have positive effects on Eberhardshof, a district lying to the west. But the Palace of Justice complex will impede the integration of the campus with the center of Nuremberg via Himpfelshof. And a southern connection will still have to be created via Fürther Straße’s aboveground subway.

What is more realistic than a new urban university campus and merger of the towns around a new midway point is to accept that a new center cannot be built on Fürther Straße. The experience of the past hundred years shows that the peripheral quality at the border between the two towns will remain even if urban development along Fürther Straße continues.

It is wrong to think that midpoint of the main connection axis between the centers of Nuremberg and Fürth can emerge as new center. The development that has occurred along Fürther Straße stands in the way of a close-meshed network and promotes the kind of large-scale structures that block passage to other districts. This case shows that city centers do not merge like water drops when they come too close; they grow by sprouting links between unconnected areas. But links created for speed and immediacy can have long-lasting effects, retaining their transitory and peripheral character far into the future. The development of Fürther Straße also shows that grid intensification cannot unfold concentrically because the areas around main access routes preserve their peripheral character even after strong urban growth. As the grid intensifies in other areas, the conservation of large-scale structures contributes to the fractal structure often observed in cities (Batty 1994). Fürther Straße cannot easily be fashioned into a Haussmann-like boulevard because the urban tissue around it has grown into a kind of peripheral organ for the city.

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ON THE CORRELATION OF PEDESTRIAN FLOWS TO URBAN ENVIRONMENT MEASURES: 
A Space Syntax and Walkability Analysis comparison case

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ABSTRACT

Today, urban planners face the challenge of making cities more walkable. A range of methodologies has been developed for “walkability” assessment, a wide range of actors are involved in the evaluation of relations between urban environment and pedestrian behaviour, and different definitions on how to measure this relation arise. Space Syntax (SSyntax) research has been a key contributor to the study of the relation between urban environment and pedestrian movement providing solid evidence on their correlation. International SSyntax research has focused on the development and comparison of built environment indicators and models, whilst the methods used for pedestrian data collection and processing used to validate such models, have somehow been overlooked. This study puts forward operational issues regarding pedestrian counts and their correlation to urban environment measures. A series of pedestrian counts was performed in a sample of 60 streets in Lisbon (approx. 10,000 counts) to validate the results of two built environment assessment methods – space syntax and walkability analysis. A very high degree of spatial-temporal variation in pedestrian flows and a very significant proportion of people sojourning was observed.

Addressing consistency, this paper presents and discusses a set of tests on the correlation strength between the pedestrian data and built environment measures. Findings point out the influence of the aggregation of pedestrian data on the correlation coefficients, suggesting that data “taming” using average values of the pedestrian flows may have implications on the interpretation of results. The results also suggest that future research on the integration of SSyntax and Walkability approaches may improve the explanatory power of pedestrian behaviour.

KEYWORDS

Pedestrian movement; Analytics; Urban metrics; Walkability; Pedestrian behaviour
INTRODUCTION

Walking is gaining growing attention as a key factor in the promotion of healthier, environmentally friendly and socially active communities. In the past decades, researchers from various science fields, namely architecture, urban planning, transportation and public health have been developing tools and measures to provide an objective answer to the question “how walkable is my street/neighbourhood/city?”.

Space Syntax (henceforth SSyntax) concerns the relation between the built environment configuration and urban dynamics. It is a concept built upon the works of Hillier and Hanson, developed in the 1970s at the University College London, establishing relations for the understanding of the impact of urban morphology on people’s movement. (Koohsari, Owen, Cerin, Giles-corti, & Sugiyama, 2016) (Pereira, Holanda, Medeiros, & Barros, 2012). Within SSyntax concept, streets can be represented as axial lines, corresponding to straight lines of sight, whose topological relations form the base of an extensive set of indicators.

Likewise, the influence of the urban built environment on pedestrian travel behaviour has been the focus of walkability assessment research. Many environmental factors have been associated with walking behaviour but agreement on the relative importance of each factor is still contentious. These factors are broadly related to street connectivity, accessibility, land use, urban design and facilities. Numerous tools and methods have been put forward to measure walkability, including audit tools, checklists, inventories, level-of-service scales, surveys, questionnaires and indices.

Albeit of different nature, Space Syntax and Walkability tools share common grounds in attempting to understand and explain pedestrian behaviour and movement. Both methods address the influence of the urban morphology in walking. SSyntax regards connectivity as a central piece of its rationale whilst a walkability tool considers it as one of the key factors amongst others.

At the operational level SSyntax analysis are somewhat more straightforward to perform as they use cartographic data as main input whilst walkability analysis demand more extensive datasets with attributes related to environmental features and land uses that, in many cases, need to be obtained by means of street auditing. The approximation of both approaches has been suggested by Cambra (2012) and more recently by Koohsari et al. (2016).

In order to trust the outcomes of these tools as accurate estimators of pedestrian movement, some kind of validation should be performed. Various methods can be applied, namely travel surveys, household surveys, interviews, questionnaires and pedestrian counts.

Within the transportation and urban planning research, the use of pedestrian counts for validation of urban design measures has been addressed by Ewing and Connors (2013) but in practical terms, such relation has been more extensively addressed within public space research. The work of Gehl and Svarre (2013) provides a comprehensive guide to various manual and automated registration methods, namely counting (often registering the pedestrian flow), mapping (more oriented to record the locations where people stay), tracing (registering movement patterns), and tracking (to address walking speeds and route events). Although more sophisticated and automated methods have been recently developed and tested, such as real time video counters or public access image databases the most used method to obtain pedestrian flows is still the “gate” method in which a standing observer counts the pedestrians that cross an imaginary line in front of him (Vaughan & Grajewski, 2001). Using this straightforward method, the Space Syntax research community has been a significant contributor to the understanding of the relation between built environment attributes and pedestrian volumes, providing consistent evidence of a positive and significant relation between the network connectivity and the pedestrian activity (B. Hillier, Penn, Hanson, Grajewski, & Xu, 1993)(Hillier & Iida, 2005)(Kalakou & Moura, 2014) (Hajrasouliha, 2015).
Space Syntax theory suggests that the amount of movement occurring on each street is influenced by its configuration and by the relation that each street establishes with the other streets in the urban system. The spatial distribution of flows in the system is therefore essentially morphological and topological, being a functional result of the urban configuration (Pereira et al., 2012).

The seminal work of Hillier et al. (1993) analysed the relation between the configuration of the King’s Cross area in London and the observed pedestrian movement. A positive and significant degree of correlation was found between the pedestrian flow and SSyntax indicators (connectivity, integration, control and global choice), of which “integration” was found to show the strongest association. Using simple linear regression between pedestrian movement rates and integration, a coefficient of determination (R²) of 0.238 was obtained. A higher R² was obtained (0.547) when using the natural logarithm of pedestrian movement rates. The degree of correlation also increased when each of the 10 subareas of the global study area was analysed individually, ranging from 0.617 to 0.798, meaning that almost 60 to 80% of the variation in the pedestrian movement rates could be explained by configurational aspects only.

Similar tests in different places have reached similar results in the demonstration of positive and significant associations between pedestrian movement and urban configuration, being the explained variation of pedestrian flow consistently in the range of 60-70% (Lerman, Rofè, & Ömer, 2014).

At this stage it is worth noticing that, albeit pedestrian movement has been the key for the calculation of correlation indices by the SSyntax approach, sojourning pedestrians (people sitting, standing, socializing) can be a significant part of the pedestrian activity on the streets. Hence we can pose the question of how the degree of correlation would be affected if both moving and static pedestrians would be considered in pedestrian counts. In fact, the observations of Hillier et al (1993) reported “encounter rates” with moving and static pedestrians but only movement rates were used in the study. Another interesting take drawn from this work was the use of a “moving observer” technique in order to capture movement and static pedestrians. An adaptation of the “moving observer” technique, which we used for collecting the pedestrian counts, is described in the next section.

In this sense, adding the walkability perspective, it is expected that a friendlier walking environment, where connectivity plays a major role (SSyntax measures) but where attractiveness factors are also relevant (walkability analysis), will be associated to higher pedestrian activity (moving and sojourning pedestrians).

A series of pedestrian counts was performed in order to validate the walkability assessment tool developed by Moura et al (2017) and a series of consistency issues relating to pedestrian counting and correlation analysis were identified. This paper focus on the consistency issues identified in collecting and processing the pedestrian counts, and in its potential implications in calculating correlation indices. In addition, by performing SSyntax analysis to the studied area, we were able to compare the correlation between pedestrian volumes, SSyntax measures and Walkability scores.

2. BUILT ENVIRONMENT MEASURES: SPACE SYNTAX AND WALKABILITY SCORES

We used two methods for measuring the built environment in relation to pedestrian behaviour: the SSyntax methodology and a walkability assessment framework.

The studied areas were located in Lisbon, Portugal Arroios (Study Area 1) and Avenidas Novas, (Study Area 2), both located in the city central area.

Study Area 1, Arroios: It is a mixed use area with predominant residential occupation formed by 4-6 story buildings. Its urban development was initiated in the early 20th century, having registered a major progress within the years 1919-1945. It is composed by a mix of regular and irregular street pattern of one to two lane road spaces. It is a hilly setup with a noticeable lack of open spaces and green areas.
Study Area 2, Avenidas Novas: Resulted from a planned urban intervention in the late 19th century. It is a mixed use area formed by medium rise buildings with a significant office occupation. The street design incorporated the French boulevard style, being characterized by a regular grid of large avenues with tree alignments in the medians.

2.1 WALKABILITY SCORES

A number of walkability assessment methodologies have been developed for application in urban planning, used by planning professionals and policymakers to understand the scope and extent of local pedestrian conditions as well as to identify possible interventions for its promotion. The walkability of the environment was assessed by a tool, previously developed by the research team. This walkability framework was named IAAPE - Indicators of Accessibility and Attractiveness of the Pedestrian Environment (www.iaape.org). The IAAPE framework stands out from the majority of similar tools due to its participatory nature, by involving the main stakeholders into the selection and ranking of the indicators that structure the backbone of the pedestrian environment assessment. It also allows the measurement to meet distinct pedestrian groups and trip purposes. Similarly to other walkability tools, the IAAPE framework assesses the pedestrian environment by performing street audits. A set of indicators related to 7 key dimensions (Connectivity; Convenience; Comfort; Conviviality; Conspicuousness; Coexistence; Commitment) is used to score the street environment qualities. Data is collected and stored in a GIS platform where a pedestrian network was previously built, representing the extent of the pedestrian realm (sidewalks, crossings, footpaths and corresponding attributes — for instance, curbed sidewalks for inclusive accessibility) in a more accurate way than commonly used road centreline networks. The digital pedestrian network is also used to compute the Connectivity indicator by using the Network Analyst tool of ArcMap © GIS software. The Connectivity indicator uses the formulation of Cambra (2012) consisting in the ratio of the network distance and the straight-line distance between specific origins and destinations.

The IAAPE tool uses a simple multicriteria compensatory model, where the walkability score of a street segment (link) is obtained by adding the 7 C’s indicators multiplied by their relative weight, being represented on a 0 to 100 scale. For a more comprehensive description on the framework refer to Moura et al. (2017).

The IAAPE framework was used to assess the walkability of Arroios (Study Area 1) and Avenidas Novas, (Study Area 2), providing walkability scores for approximately 800 street segments. Comparing the two areas in terms of aggregated walkability scores (classified in 5 categories...
from A to E) significant differences are found: In Arroios, the majority (67%) of the pedestrian network falls in an average classification (C: score between 40 and 60), with 10% of the network scoring below 40 (categories D and E). Only 22% of the network is in category B, whilst streets with high walkability scores were not present in the area. In the other study area, Avenidas Novas, the differences in the walking environment is quite noticeable. The majority (70%) of the pedestrian network scores B and there are more streets of higher walkability (2% in category A) than there are of lower walkability (less than 1% in categories D and E). The remainder 27% score C.

2.2 SPACE SYNTAX MEASURES

For the SSyntax measures for the study area we used the axial map of the city of Lisbon (previously developed by the SSyntax research group at Instituto Superior Tecnico – University of Lisbon) and Depthmap software v.10. We obtained 3 common spatial measures: connectivity, global integration and local integration (R=3). The connectivity index, which reflects the number of axial lines directly intersecting each line in a network, was much higher in Avenidas Novas (10.42) than in Arroios (5.57), reflecting its grid pattern. The integration index, which reflects the average topological distance, that is to say the number of direction changes from each line to all the other lines in a network, was relatively similar in both areas (Arroios=0.56; Avenidas Novas=0.65) relating to their central position in the system.

The local integration index (with a radius of 3) which reflects the topological proximity of a line to its nearby axial lines (in this case two turns away from a given axial line) was also relatively similar and slightly higher in Avenidas Novas (2.86) than Arroios (2.86). Both areas show some of the highest values for local integration found in the city of Lisbon.

3. PEDESTRIAN DATA

3.1 COUNTING METHOD AND ACCURACY ISSUES

Two observation methods were considered two collect pedestrian data to validate the built environment measures: the gate method and the moving observer method. For the validation of the built environment measures we wanted to address different travel purposes of walking. Considering utilitarian travel to be more related to movement and social/recreational travel to be related to sojourning, we ought to collect data on moving and static pedestrians. According to the Space Syntax Observation Manual (Vaughan & Grajewski, 2002), “the gate method is the workhorse of spatial observing techniques”. It is a simple and widely adopted method consisting of observing the people (or vehicles) passing through an imaginary screen line crossing the street space at a right angle, being suitable for recording moving people but not for stationary people.

The moving observer method, on the other hand, is suitable to record moving and static pedestrians, having been used with slight variations in SSyntax research (B. Hillier et al., 1993) (Choi & Koch, 2015). In this method the observer walks at a regular pace along the street, counting people in movement (in the same direction of the observer, opposite direction or both) and static people (seating, standing).

In order to increase accuracy and reliability, the moving observer method demands several passes in each way. Sample size was determined on preliminary observation of the pilot study whereby every street segment of 4 blocks was analysed in the same area, with 4 counts each. Based on the results (mean; variance) 30 observations per street segment was found to bind the standard error to a 10% range relative to the mean, attending to the high variance of pedestrian flows. The number of needed observations is in line with Hillier’s method, which required routes to be observed “between twenty to thirty times”.

ON THE CORRELATION OF PEDESTRIAN FLOWS TO URBAN ENVIRONMENT MEASURES: A Space Syntax and Walkability Analysis comparison case
Given the high variance of pedestrian flows, even a large number of observations per street (30) did not assure a standard error of 10% for each street of our study area. Figure 2 illustrates the error in the relation to pedestrian count results, showing that for pedestrian flows lower than 80 people per 15 minutes the standard error tends to be higher than 10% and higher than 20% for a pedestrian flow lower than 20 people/15 mins.

The location of the counting spots is another critical subject. The Space Syntax Observation Manual recommends a minimum of 25 “gate” positions placed in a manner to cover a range of pedestrian volumes (“well- used, moderately used and poorly used spaces in and around the area of study”). To capture the area’s environmental variety thus covering a full range of pedestrian volumes, the pedestrian network would have to be typified prior to performing the sample selection. In order to obtain a somewhat more refined street typology set, the option was to group streets according to their attributes, in terms of the 7 key dimensions, and their global quality, in terms of their walkability score. Using the statistical software SPPS “n-cluster analysis” we obtained 4 typology clusters comparable to a “street hierarchy”. A sample size of 60 street segments (approx. 5% of the total) was considered sufficient to ensure the representation of each “hierarchy”. The counting locations were randomly selected for each street typology at first, but, as we used the moving observer method, the physical effort needed to perform the observations had to be considered (street length, street to street distances and slope). Given that all the observations made by a single person were required to be made within a 90 minute time period it was necessary to refine the counting locations by manual screening.

The Arroios study area was divided in 6 sections (36 streets to be observed) and Avenidas Novas study area was divided in 4 sections (24 streets), totaling 60 streets to be observed. The team of counting auditors consisted of 10 students from the University of Lisbon who received training prior to the field work, and were supervised by a coordinator on the field.

In short, the counting procedure consisted on the simultaneous counting of a sample of 60 street segments, by a team of 10 auditors, during 5 week days plus a Saturday. Each street segment was observed 6 consecutive times in 5 different time periods (3 time periods on the Saturday). Concerning observation periods, each street segment would be observed at 5
distinct daily periods consisting of the morning peak (8:00-9:30 AM); morning off-peak (10:00-11:30 AM) lunch peak (12:30-14:00 PM); afternoon off-peak (15:00-16:30 PM) and afternoon peak (17:00-18:30 PM). This method would provide 10,080 distinct pedestrian counts (60 streets*6 counts*5 periods*5 weekdays + 60 streets*6 counts *3 periods*1 Saturday). The survey was performed from May 7th to 13th, 2015, (Thursday to Wednesday, excluding Sunday). The weather conditions were stable and consistent to the time of the year - sunny days with average temperatures of 20º C, with the maximum temperature reaching 30º C in the last 3 days. The location of the streets where the counting took place is provided in Figure 3.

After performing data consistency tests, we obtained a total of 9,136 valid counts from the 10,080 collected observations, resulting in 4,568 count values (1 count value is made of 2 way and return observations). One of the reasons dealt with human error related to accuracy when recording the travel times. Another reason dealt with human fatigue. Although the observations circuits were designed to minimize walking distances there were cases where the counting auditor was not able to complete the observation circuits within the planned time limits, especially during the warmer periods. The counting auditors walked an average of 20km per day. The results for the built environment measures and pedestrian counts for each study areas are presented in Tables 1 and 2.
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<th>Street Ref.</th>
<th>Walkability Score</th>
<th>Average Moving Flow (ped/15 mins)</th>
<th>Average proportion of sojourning people (%)</th>
<th>Connectivity</th>
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Table 1 - Built environmental measures and pedestrian counts per street segment, Area 1 – Arroios
ON THE CORRELATION OF PEDESTRIAN FLOWS TO URBAN ENVIRONMENT MEASURES: 
A Space Syntax and Walkability Analysis comparison case

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Table 2 - Built environmental measures and pedestrian counts per street segment, Area 2 – Avenidas Novas

3.2 SPATIAL-TEMPORAL VARIABILITY

The above tables underline the spatial variability of pedestrian flows, as very different movement patterns are found not only in streets located within the same study area but in different segments along the same street. Temporal variability is easily noticeable throughout the different day periods.

The spatial-temporal variability of pedestrian flows results in a high volatility of pedestrian counts at individual locations, which can be an issue when performing correlations between pedestrian volumes and built environmental measures. This issue has been addressed within SSpace Syntax research by Park (2013), who analyzed an extensive pedestrian count database of about 10,000 locations in Seoul. Park found that 29% of the total variations in pedestrian counts were temporal, independently of count locations with the remaining 71% of the variation being spatial, across different counting locations, independently of count occasions. Park also noted the strong skewness of the distribution of pedestrian counts over time. In order to obtain a clear pattern of pedestrian movement, a log transformation was considered necessary but not sufficient to “tame” the distribution. Only when using average values a daily routine pattern of pedestrian movement was noticeable.
The spatial-temporal variability and the “taming” of pedestrian counts are illustrated in figures 4 and 5. Figure 4 shows the recorded pedestrian flows for one of the sampled streets (Ref.1006 in study area 2) during a week. It can be seen that each observed day shows a different behavior and no discernible pattern can be found. When these values are averaged (Figure 5) it is possible to notice a daily routine where most people are found walking during the lunch hour peak. This observation makes sense within the area’s land use context: there are many offices and people leave the offices to eat out during lunch time. The pedestrian volume at the morning and afternoon peak hours is lower than the one at lunch time probably because many office buildings have their own car parking so people do not walk to access their workplace. Of course, it can be questioned is if the averaged volume value can be considered a “typical” daily pattern as it is not observable in more than 1 of the 5 week days. Likewise, the flow pattern of a street attained from the values observed in its constituent parts (segments) is very likely an amalgamation of dissimilar travel patterns that do not follow a particular trend unless all segments’ observations are combined and averaged values.

Analyzing the 60 sampled streets and respective 4,568 counts, we could conclude that using average values allowed having a clearer notion of the flow patterns but disregards the intrinsic and characteristic spatial-temporal variation of pedestrian movement, possibly inducing bias in the correlation analysis. Location specific spatial-temporal variation of the pedestrian volumes should be taken into consideration when designing the pedestrian counting procedure: where to count, for how long and how many different days to count.

![Figure 4 - Pedestrian flow of street segment 1006 over a week](image)

![Figure 5 - Average pedestrian flow of street segment 1006 over a week](image)
4. CORRELATING BUILT ENVIRONMENT MEASURES AND PEDESTRIAN DATA

Given the high spatial-temporal variability of pedestrian flows and the significant proportion of sojourning pedestrians (not moving) we run a series of tests, correlating the pedestrian data with built environment measures (SSyntax indices and Walkability scores).

In the first test, we addressed spatial variability. We used the pedestrian data obtained for the sample of 60 streets. In Arroios, 36 streets were observed for a week in a total of 2700 observations (resulting from 5400 individual observations in each direction). In Avenidas Novas, 24 streets were observed for a week in a total of 1382 observations (resulting from 2764 individual observations in each direction). In this test the pedestrian data was not linearized (using a log transformation) nor summarized (using average values). The obtained Pearson Correlation coefficients (r) show significant differences for each area and for the SSyntax and Walkability approaches, being the highest correlation value observed between the pedestrian flow and walkability scores (r=0.461; R²=0.212).

We note three interesting findings here: i) the highest correlation value to SSyntax measures is related to connectivity, not to integration; ii) the correlation values to SSyntax measures are significantly higher in the area that shows a regular grid pattern and high pedestrian volumes; iii) the opposite happens with the correlation values to Walkability scores (higher correlation values in the area that shows an irregular pattern and lower pedestrian volumes).

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<tr>
<td></td>
<td>Connectivity</td>
</tr>
<tr>
<td>Arroios (N=2700)</td>
<td>0.321**</td>
</tr>
<tr>
<td>Avenidas Novas (N=1382)</td>
<td>0.515**</td>
</tr>
<tr>
<td>Global (week days, N=4082)</td>
<td>0.430**</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3 - Spatial variability test (per study area)

For the second test we aggregated the pedestrian counts of both areas by counting period in order to address temporal variability during the day. We can observe that the correlation coefficient varies along the day, being highest at the lunch hour peak period and that the temporal variation is lower than spatial variation of the previous test (much in line with Park results for Seoul (Park, 2013). Again, the highest correlation coefficient is obtained for the walkability scores (r=0.525; R²=0.275).
The third test was similar than the previous one, with the difference that the temporal aggregation was made by counting day, including the Saturday. We note two interesting findings here: i) pedestrian flow correlations vary significantly along the week days (more than 30% in the case of Integration) showing that picking a “typical day” to perform pedestrian counts may introduce distortion in the correlation analysis results; ii) It is noticeable the change in r between any week day and the Saturday. However, the walkability scores’ r remains more consistent over the week (less than 15% variation) than the Space Syntax’s r (more than 40% variation).

**Table 4 - Temporal variability test (per counting period)**

<table>
<thead>
<tr>
<th>Flow (pedestrians/15 min)</th>
<th>Pearson Correlation (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Connectivity</td>
</tr>
<tr>
<td>P1 (08:00-09:30; N=826)</td>
<td>0.419**</td>
</tr>
<tr>
<td>P2 (10:00-11:30; N=822)</td>
<td>0.389**</td>
</tr>
<tr>
<td>P3 (12:30-14:00; N=809)</td>
<td>0.471**</td>
</tr>
<tr>
<td>P4 (15:00-16:30; N=813)</td>
<td>0.478**</td>
</tr>
<tr>
<td>P5 (17:00-18:30; N=812)</td>
<td>0.420**</td>
</tr>
<tr>
<td>All Periods (week days; N=4082)</td>
<td>0.430**</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

**Table 5 - Temporal variability test (per day of the week)**

<table>
<thead>
<tr>
<th>Flow (pedestrians/15 min)</th>
<th>Pearson Correlation (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Connectivity</td>
</tr>
<tr>
<td>Monday (N=813)</td>
<td>0.497**</td>
</tr>
<tr>
<td>Tuesday (N=810)</td>
<td>0.394**</td>
</tr>
<tr>
<td>Wednesday (N=810)</td>
<td>0.394**</td>
</tr>
<tr>
<td>Thursday (N=839)</td>
<td>0.413**</td>
</tr>
<tr>
<td>Friday (N=810)</td>
<td>0.443**</td>
</tr>
<tr>
<td>Saturday (N=486)</td>
<td>0.292**</td>
</tr>
<tr>
<td>Week days (N=4082)</td>
<td>0.430**</td>
</tr>
<tr>
<td>All days (N=4568)</td>
<td>0.415**</td>
</tr>
</tbody>
</table>

**Correlation is significant at the 0.01 level (2-tailed).**

**Table 4 - Temporal variability test (per counting period)**

**Table 5 - Temporal variability test (per day of the week)**
Next, we addressed pedestrian activity in the streets – that is moving and sojourning people - in comparison to pedestrian flows. In the following tests we applied a natural log transformation to the pedestrian flow and analyzed each study area independently. The observations for all days were used (week days and Saturday).

### Area 1 - Arroios

<table>
<thead>
<tr>
<th>N = 3,024; 36 streets</th>
<th>Connectivity</th>
<th>Integration</th>
<th>Integration R3</th>
<th>Walkability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian flow (per 15 min)</td>
<td>1.322**</td>
<td>1.277**</td>
<td>1.170**</td>
<td>1.491**</td>
</tr>
<tr>
<td>Ln (PedFlow_{15min})</td>
<td>1.292**</td>
<td>1.202**</td>
<td>1.170**</td>
<td>1.456**</td>
</tr>
<tr>
<td>PedActivity (moving+sojourning)</td>
<td>0.344**</td>
<td>0.492**</td>
<td>0.659**</td>
<td>0.656**</td>
</tr>
</tbody>
</table>

### Area 2 – Avenidas Novas

<table>
<thead>
<tr>
<th>N = 1,544; 24 streets</th>
<th>Connectivity</th>
<th>Integration</th>
<th>Integration R3</th>
<th>Walkability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian flow (per 15 min)</td>
<td>1.488**</td>
<td>1.489**</td>
<td>1.515**</td>
<td>1.334**</td>
</tr>
<tr>
<td>Ln (PedFlow_{15min})</td>
<td>1.475**</td>
<td>1.465**</td>
<td>1.510**</td>
<td>1.298**</td>
</tr>
<tr>
<td>PedActivity (moving+sojourning)</td>
<td>0.355**</td>
<td>0.365**</td>
<td>0.393**</td>
<td>0.358**</td>
</tr>
</tbody>
</table>

### Aggregated areas

<table>
<thead>
<tr>
<th>N = 4,568; 60 streets</th>
<th>Connectivity</th>
<th>Integration</th>
<th>Integration R3</th>
<th>Walkability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian flow (per 15 min)</td>
<td>1.415**</td>
<td>1.254**</td>
<td>1.388**</td>
<td>1.456**</td>
</tr>
<tr>
<td>Ln (PedFlow_{15min})</td>
<td>1.377**</td>
<td>1.236**</td>
<td>1.368**</td>
<td>1.404**</td>
</tr>
<tr>
<td>PedActivity (moving+sojourning)</td>
<td>0.409**</td>
<td>0.374**</td>
<td>0.377**</td>
<td>0.496**</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

Contrary to the findings of other studies, using the natural log transformation did not result in an improvement of the correlation coefficient for the SSyntax measures (an exception was found in Arroios area). But, when using the full week dataset and the Ln transformation for each area independently then the local integration (R3) becomes the best spatial predictor for pedestrian movement.

When considering moving and static pedestrians –pedestrian activity- a lower r is found for SSyntax measures, whilst a higher r is observed regarding walkability scores. At this stage we can consider SSyntax to be better suited for explaining movement than to explain a broader street use, which includes moving, standing, sitting and socializing pedestrians, translated in the concept of pedestrian activity.

Overall the best fit to pedestrian counts is obtained by correlating pedestrian activity and walkability scores ($r=0.496$; $R^2=0.246$); which is quite lower than the results found in SSyntax research studies, and, in statistical terms, considered a weak correlation. The low explanatory power of the built environment measures (either SSyntax or Walkability scores) in relation to pedestrian volumes was striking, especially when other studies point to a coefficient of determination ($R^2$) higher than 60%, meaning that 60% of the variation of pedestrian volumes...
could be explained by the spatial/environmental attributes of the urban space. In our case, no more than 25% of the pedestrian volume variation could be explained.

Such weak correlation is linked to the high volatility of pedestrian flows. Recalling the previous section of this paper, the pedestrian flows observed on a single street segment do not allow distinguishing a clear pattern, but, when the observation values are summarized in average values, patterns become discernible. On the other hand, when using an average value we are not only discarding relevant information about variation but also reducing the sample size, thus lessening statistical significance.

We tested using the average values of the pedestrian flow for each street. This means all the 4,568 observations were summarized into 60 records prior to the correlation analysis.

The findings were considerably different: first, the best spatial predictor for pedestrian movement was now Local Integration, for both study areas; second, using the Ln transformation increased the r value to figures closer to similar studies (namely in Area 2, where the local integration r=0.737); third, the correlation coefficient of SSyntax measures and walkability scores was now very similar at the aggregated area analysis (Local integration r=0.619; Walkability score r =0.634) and fourth, some of the correlations for the individual areas were not statistically significant.

According to these values, the power of the built environment measures to explain the (average) pedestrian flow variation in the aggregated study area was now between 38% -40%, which is a significant improvement compared to the previous model specifications.

<table>
<thead>
<tr>
<th></th>
<th>Area 1: Arroios</th>
<th>Area 2: Avenidas Novas</th>
<th>Aggregated areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Connectivity</td>
<td>Integration</td>
<td>Integration R3</td>
</tr>
<tr>
<td>Pedestrian flow (per 15 min)</td>
<td>,422*</td>
<td>,232</td>
<td>,394*</td>
</tr>
<tr>
<td>Ln (PedFlow15min)</td>
<td>,402*</td>
<td>,419*</td>
<td>,533*</td>
</tr>
<tr>
<td>Pedestrian flow (per 15 min)</td>
<td>,660**</td>
<td>,671**</td>
<td>,696**</td>
</tr>
<tr>
<td>Ln (PedFlow15min)</td>
<td>,660**</td>
<td>,684**</td>
<td>,737**</td>
</tr>
<tr>
<td>Pedestrian flow (per 15 min)</td>
<td>,560**</td>
<td>,346**</td>
<td>,524**</td>
</tr>
<tr>
<td>Ln (PedFlow15min)</td>
<td>,537**</td>
<td>,502**</td>
<td>,619**</td>
</tr>
</tbody>
</table>

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 7 - Correlation coefficients of average pedestrian flow values in Area 1
5. CONCLUSIONS

In summary, our tests showed that the spatial-temporal variations inherent of pedestrian flows can induce relevant changes in the correlation analysis between pedestrian volumes and built environment measures.

Also, the use of average values can introduce potential bias in the correlation analysis. This is a very pertinent issue when realizing that within SSyntax research there is a considerable body of evidence built upon the correlation of spatial predictors to pedestrian volume. The omission or the unclear description of the pedestrian counting procedures at the observation stage and at the processing stage may result in unfeasible comparisons between models and unfeasible transferability of findings.

The introduction of a potential bias in the result is illustrated in Table 10 which summarizes the discussed correlation analysis and shows how the correlation coefficients vary according to the pedestrian dataset used. Looking at the Local Integration correlation values to the log of pedestrian flow it can be seen that the use of “raw” data results in \( r=0.368 \), which is considered a weak correlation whereas the use of “tamed” data results in \( r=0.619 \), which is already a moderate to strong correlation. In conclusion we can admit the use of both “raw” and “tamed” pedestrian data but this should be a conscious option.

<table>
<thead>
<tr>
<th>Counting period</th>
<th>Pedestrian volume variable</th>
<th>N observations</th>
<th>Connectivity</th>
<th>Integration</th>
<th>Local Integration (R3)</th>
<th>Walkability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week days (Mon:Fri)</td>
<td>Pedestrian flow / 15 mins</td>
<td>4082</td>
<td>0.430</td>
<td>0.268</td>
<td>0.404</td>
<td>0.461</td>
</tr>
<tr>
<td>Week days + Saturday</td>
<td>Pedestrian flow / 15 mins</td>
<td>4568</td>
<td>0.415</td>
<td>0.254</td>
<td>0.388</td>
<td>0.456</td>
</tr>
<tr>
<td></td>
<td>LN (pedestrian flow / 15 mins)</td>
<td>4568</td>
<td>0.377</td>
<td>0.236</td>
<td>0.368</td>
<td>0.404</td>
</tr>
<tr>
<td></td>
<td>Pedestrian activity (moving+static)</td>
<td>4568</td>
<td>0.409</td>
<td>0.274</td>
<td>0.377</td>
<td>0.496</td>
</tr>
<tr>
<td></td>
<td>Average pedestrian flow / 15 mins</td>
<td>60</td>
<td>0.560</td>
<td>0.346</td>
<td>0.524</td>
<td>0.582</td>
</tr>
<tr>
<td></td>
<td>LN (average pedestrian flow / 15 mins)</td>
<td>60</td>
<td>0.537</td>
<td>0.502</td>
<td>0.619</td>
<td>0.634</td>
</tr>
</tbody>
</table>
The highest explanatory power of the built environment measures to explain the pedestrian flow variation was found to be in the 40% range, being very similar between the SSyntax approach (38.3%) and the walkability approach (40.2%).

The walkability score approach was found to deliver more consistent correlates over the issue of spatial-temporal variability and over pedestrian travel behavior, dealing with moving and sojourning pedestrians. As walking can be associated to different travel purposes – utilitarian/social/recreation – and different travel purposes can be related to distinct activity patterns, then addressing a full range of pedestrian activity patterns would be of interest of research on the built environment, physical activity and health.

Table 8 - Summary of the correlation analysis: Pearson correlation

<table>
<thead>
<tr>
<th>Counting period</th>
<th>Pedestrian volume variable</th>
<th>N observations</th>
<th>Coefficient of determination (R2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week days (Mon:Fri)</td>
<td>Pedestrian flow / 15 mins</td>
<td>4082</td>
<td>18.5%</td>
</tr>
<tr>
<td></td>
<td>Pedestrian flow / 15 mins</td>
<td>4568</td>
<td>17.2%</td>
</tr>
<tr>
<td></td>
<td>LN (pedestrian flow / 15 mins)</td>
<td>4568</td>
<td>14.2%</td>
</tr>
<tr>
<td></td>
<td>Pedestrian activity (moving+static)</td>
<td>4568</td>
<td>16.7%</td>
</tr>
<tr>
<td></td>
<td>Average pedestrian flow / 15 mins</td>
<td>60</td>
<td>31.4%</td>
</tr>
<tr>
<td></td>
<td>LN (average pedestrian flow / 15 mins)</td>
<td>60</td>
<td>28.8%</td>
</tr>
</tbody>
</table>
The walkability approach is also more resource intensive. It requires collecting and processing extensive attribute datasets, relying many times in qualitative analyses that are prone to a high degree of subjectivity. From the application of both methods (SSyntax and Walkability) in the same study areas we found a minor difference (2%) between the respective coefficients of determination. Hence we may pose the question – is it worth it? Given the major strengths of each side – the pragmatism and the decades of collaborative international research of SSyntax; and the robustness and consistency of walkability analysis – further research and experimentation is needed on the integration between SSyntax and Walkability measures.
REFERENCES


HOW EXCLUSIVE DO WE WANT TO BE?
Exploring the University Realm in the Contemporary Urban Territory

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ABSTRACT

Universities are currently experiencing a context of change and opportunity, resulting from several initiatives related to the ever greater interest in establishing knowledge economies. Fresh booms in the demand for higher education worldwide, associated with growing evidence of the potential benefits resulting from the economic appropriation by society of the results and methods of scientific investigation, have changed the perception of the “academic divide” and emphasised the benefits of investing in knowledge-based urban development.

This paper is based on the premise that universities play a critical role in urban dynamics because of their potential effect in enabling and promoting the development of synergies that strengthen urban vitality, as well as public and academic life. While they are integrated urban entities, they must also be able to foster interaction among (and outside) the academic community, without losing their specificity and individual character.

The ultimate goal of the paper is to allow for a description of the location properties that affect a university precinct’s ability to become fully integrated and embedded in its host city’s urban dynamics while, at the same time, preserving its uniqueness and spatial identity in such a way as to guarantee suitable places for learning and its related intellectual activities. The paper is based on a multiple case-study research, combining morphological descriptions with empirical in-situ observation. This spatial reasoning presupposes two main considerations: firstly the ability to identify invariants and relationships within the actual realisations and, secondly, to recognise and discover general types, i.e. The genotypes.

A 52-case sample, selected according to the urban situation and morphological features of each precinct, provided the information that was needed to identify the principles underlying the organisation of eight different university precinct genotypes. The relationships between the universities and their host cities were later clarified by means of axial and segment analysis, making it possible to emphasise configurational patterns within each type.

The paper consists of three parts: the first part presents the methodological procedures that were followed; the second part describes the eight types and their morphological features; and the third part explores the syntactic properties of each type. From the identification and
characterisation of the types, some patterns emerge, revealing common features in relation to
the host city and affording a deeper understanding of the levels of morphological integration
that university precincts can achieve.

KEYWORDS
University precinct, morphology, permeability, boundary, spatial reasoning, university-city
synergy.

1. INTRODUCTION
Assuming that universities play a dominant role within the context of the knowledge economy,
this paper examines the configurational features that can contribute positively to the integration
and development of university precincts in urban & social areas. The purpose is to identify
location properties that influence the precinct’s ability to become integrated and embedded
in its urban setting. University precincts are defined as the areas occupied by a university and
where its functions and activities take place.

As Temple (2009, 2014) advocates, the physical space is one of the most powerful tools
available for the university to express and convey its identity, namely its values, mission and
cultural background. Not only is the university able to express its identity through the physical
space (Edwards 2003, Hajrasouliha and Ewing 2016), but it can also communicate its presence,
purpose and domain (Dober 1992). Furthermore, precinct configuration, including proximity
and adjacency relationships, can foster exposure and interactions that permit successful
collaborations and outputs (Kenney et al. 2005).

Several authors emphasise the importance of establishing relationships, connections and
synergies between university precincts and their host cities (Gibbons et al. 1994, Conceição
Nevertheless, there is a shortage of literature focusing on the description of the spatial properties that enable these relationships and which may, in particular, contribute
towards supporting urban activity and vitality in a balanced and sustainable manner, i.e.
without forgetting that university precincts are academic facilities requiring a spatial identity
that guarantees adequate places for learning and its related intellectual activities.

According to Engwicht, “cities were invented to facilitate exchange of information, friendship,
material goods, culture, knowledge, insight, skills, and also the exchange of emotional,
psychological, and spiritual support” (1992, p. 17). And so were university precincts. Space
quality can inform and impact on human behaviour and activity, and there is a close connection
between the qualities of the urban space and the quality of the activities performed there
(Whyte 1980, Beck 2009). Such an inference from public space to university space is possible,
and one can argue that there is a close connection between the quality of a university’s physical
space and the quality of university life.

Despite the difficulty of limiting the impact of spatial variables while analysing universities, it
is possible to identify some key aspects that can serve to enhance perception of a university’s
physical integration within its host city. Location is a crucial feature in increasing a university’s
visibility and the movement taking place to and through the precinct. Furthermore, since this
is one of the hardest and most costly features to change, the amount and type of boundaries
and the presence of barriers can deeply affect the way in which city and university relate. The
existence of links connecting the interior of the precinct to its surrounding neighbourhood can
also be a key factor in establishing stronger connections.

In face of the importance of the physical space of the university, particularly considering it is
the first available link connecting the university to its hosting city, this paper aims at identifying
patterns of precinct location within hosting cities, on an attempt to identify positive scenarios
for university physical integration. It relies on the premise that there are eight university
precinct genotypes, according to their morphological features, and that these present different
urban behaviours.
2. METHODOLOGICAL PROCEDURES

This paper is based on a multiple case-study research (Cannas da Silva 2017), undertaken with the purpose of providing an understanding about the configurational properties of a broad set of university precincts in an attempt to identify general conditions.

This required a methodological strategy that was sufficiently rigid to allow for a comparison of different cases and to search for possible generalisations, while, at the same time, being sufficiently flexible to accommodate all the specific details that, although varying from case to case, make it possible to understand the spatial identity of a university precinct. The specificity of each case makes it possible to construct the distinctiveness of the object of study, in an integral manner.

In order to pursue this main goal, it was necessary to identify the genotype of the university precincts. Genotype is taken to mean the “abstract rules underlying spatial forms,” (Hillier and Hanson 1984, p. 12) i.e. an identifiable pattern, “one which could be detected in the configuration itself rather than in the way in which it was interpreted by minds”(Hanson 1998, p. 32). This pattern can be modified to a “greater or lesser extent in different physical circumstances, but always within limits which can themselves be specified” (Hillier and Hanson 1984, p. 38). These modifications correspond to different phenotypical situations.

Firstly, a set of 52 exemplificative cases was defined, grounded in the literature and experiential knowledge about the topic. The cases were selected according to the urban situation and morphological features of the precinct, considering the relationship between the university and the host city.

Secondly, twelve spatial variables were chosen in order to better describe the relationship between each university precinct and its surrounding urban environment - location; accessibility; boundaries; limits; density; compactness; distribution; landmarks; green elements; circulation; paths; size. Comparisons were made focusing on the relationship of the university precinct’s fabric with the adjacent urban fabric, requiring an understanding of both the “university precinct boundary” and its relative “permeability”, as well as the precinct’s spatial complexity.

An evaluation scale was drawn up for each variable, in order to permit a direct comparison between cases and to make it possible to extrapolate from the set of cases analysed, establishing “types” against which each case could be compared.

Thirdly, one example from each type was chosen as representative and analysed according to its urban insertion, using space syntax methodological procedures and tools (Hillier and Hanson 1984, Al-Sayed et al. 2014). At this stage, university precincts were analysed on a larger scale, considering the whole urban environment, in order to identify their underlying patterns and structures. In order to compare the urban qualities of each type, axial maps were analysed, focusing on two main variables: integration and choice. Integration makes it possible to measure the ease of access from any other point in the system, showing the potential of the university surroundings to be a destination, or, rather, showing whether the university premises are located in a place with the potential to serve as a destination in terms of roaming movements. Choice was used to assess the potential of the precinct to be located in a place that enables “passing-by” movement, and to enable serendipitous relationships between academics and outside users.

Segment maps were used as the basis for comparison. Normalised angular choice (NACH) and normalised angular integration (NAIN) complement the axial analyses of integration and choice (Hillier et al. 2012). Only the segment where the main entrance to the precinct is located was considered. In open precincts, with no clear main entrance, a street was identified as the location that was most visible for the university users and the one that was most used. Host cities and university precincts are analysed by being compared, in terms of their foreground and background structures. This analysis makes it possible to understand whether a university is positioned within the foreground or the background network of its host city, thus informing about its character and potential for attracting movement. When the precinct is located in the foreground network, it is likely to be frequently crossed in random movements, to be visible
within the urban system, to behave as a landmark and a reference point within the city. In contrast, when the precinct is located within the background network, it tends to be more frequently appropriated by the neighbourhood and more likely to be used as a part of it, but it can be disregarded as an important element for the city as a whole. Hence, it is less likely to be used as a path in the course of random movements, but rather to be visited only if it is a specific destination. In all cases, university premises do not have the structure to be part of the foreground network as a whole. Instead, their precincts are an integral part of the background network. It is the proximity to the foreground, or the fact that some of the segments included in the university precinct are part of the foreground network, that changes its likelihood to be used as a path by outsiders.

3. TYPES OF UNIVERSITY PRECINCTS

Eight university precinct types were identified as unique and distinct from each other, representing different modes of university spatial integration within the host city.

**Autonomous precincts** establish minimum ties, or even none, with the closest city, as illustrated by the Simon Fraser University precinct in Burnaby, Canada. These precincts, evoking the traditional University “Utopia of Insularity”, need to host all activities consistent with the permanent presence of people, so that all users (students, teachers, researchers, and administrative and ancillary staff) do not need to commute or to leave the precinct on a daily basis. Leisure facilities and activities are also provided.

**Attached precincts**, exemplified by the Aalto University Precinct in Espoo, Finland, maintain their self-sufficiency and independence from the city, seeking some degree of seclusion by being located in the outskirts. They establish a relationship of proximity that allows for the establishment of some connections.

**Inner precincts** are fully integrated into the urban fabric, but still include all the functions necessary for the permanent residence of people, such as the MIT precinct in Cambridge, Massachusetts. In this type, the university precinct is located within an urban area, establishing connecting nodes with the adjacent areas and distinguishing itself morphologically from the urban fabric.

**Developer precincts**, such as the Yale University precinct in New Haven, Connecticut, are responsible for a large part of the city's development and assume very prominent positions in the urban fabric that surrounds them and develops mostly concentrically therefrom. They tend to host a high percentage of the global population of the settlement, offering all the required living functions.

**Self-enclosed precincts**, exemplified by the IST precinct, in Lisbon, are located within the city's urban fabric, but with a strong inner-focused structure, behaving as islands within the urban area. They are characterised by their detachment from their urban surroundings, in spite of their central location.

**Open precincts**, such as the UCL precinct in London, do not present clear boundaries separating them from their surroundings, but establish a relationship of morphological continuity in terms of their scale, their main sightlines and their pathways, construction density or volumetric relations and proportions. Architectural elements are often used to establish a difference from the surrounding environment.

**Scattered precincts** spread throughout the cities, consisting of a series of separate and independent buildings, even when they are located in geographical proximity. They are exemplified by the case of UniBG, in Bergamo, Italy.

**Ubiquitous precincts** are completely intertwined with the city, becoming entities that are indistinguishable from the rest of the urban fabric, such as the precinct of the Université Catholique de Louvain, in Louvain-la-Neuve, Belgium.
4. SYNTACTIC PROPERTIES OF EACH TYPE

Some other patterns are revealed by the syntactic analysis. The percentage of axial lines that the precinct occupies varies substantially, from 0.2% of the total of the city, in the cases of London and Lisbon, to 11% of the urban region, in the case of Louvain-la-Neuve. This value alone is not an accountable measure of the university’s impact on the area, yet it nevertheless clearly affects the university’s visibility and its influence, because of the fraction that it occupies and dominates within the urban territory.

The case of Burnaby – an autonomous precinct – shows very low values of integration within the city, but high choice values. This means that the precinct is probably not used by the outside community as part of their environment, but is instead an area that they pass through on their travels across the Burnaby mountain.
Espoo—representing the attached precinct—shows a mean integration value above the average for the city as a whole, and a low mean choice value within the precinct, despite the very high value of choice of its main access. These values are probably influenced by the fragmentation of the city's urban fabric, since it would be expected that the mean integration value of the precinct would be lower than that of the city. The choice values, however, are easier to explain. Within the precinct, most of the streets do not belong to the shortest path between origins and destinations for the whole system. Nevertheless, the main access route corresponds to one of the few axes connecting Espoo to Helsinki, in the East, especially in the southern area of both cities.
The case of Cambridge, Massachusetts – representing the inner precinct – is distinct from the others. The presence of the university exceeds that of MIT, since Harvard University also occupies an important position within the city itself. Together, they add up to a very large portion of the urban fabric, and consequently of the axial lines. In this particular case, the university becomes extremely relevant for the context in which it is inserted, and both universities benefit from the presence and direct competition of the other. However, considering only MIT, both mean integration and mean choice do not present very high levels, probably due to its location on the edge of the city. If we considered Greater Boston instead of Cambridge as limits for the urban region, however, the results would be very different, and MIT would occupy the centre of the region. Nevertheless, considering the importance of MIT and its precinct for the cities of Cambridge and Boston, its low integration and choice values do not diminish its urban capacity or urban attractiveness, since the precinct can act as both an attractor and a generator of movement. Still, if we consider only its topological accessibility, and disregard the fact that MIT's premises are landmarks within the city of Cambridge, the precinct is located in an area that does not support its visibility or make it an attractive destination within the surroundings for external users.
The case of New Haven – a developer precinct – is unique. In this case, the university precinct overlaps with the integration core: it is the centre of the urban settlement both in terms of closeness and betweenness centralities, becoming a very attractive place, whether just to pass through on any journey, for the accessibility that it provides, or becoming a destination due to its configurational properties.
Lisbon – representing the self-enclosed precinct – demonstrates the case in which, even though the precinct shows very high integration values, its morphological traits can cause it to be segregated in its urban surroundings. The IST precinct shows very high mean integration and mean choice values, which make it highly visible and prone to be walked by or crossed through in random movements, and to become a destination through the configuration of the urban fabric in its area. Nevertheless, its morphology contradicts this effect: even though it is highly visible, and several movement flows pass by it, it does not become an attractive destination, used by the outside community.
On the other hand, London – representing the open precinct – presents the closest values to Lisbon, proving that, even though location plays a major role in university integration, it is not the only factor, and that morphological traits do impact on the perception of the university. The UCL precinct is very likely to be passed through on random travels, making it extremely visible to most of the population in the city, but it can also easily become a destination, based on its configurational properties. Therefore, the UCL precinct can be successful in attracting people from the outside community, based on its topology, and by promoting synergies at several levels.
Bergamo – an example of the scattered precinct – shows low mean values of both integration and choice despite the number of premises that it occupies and thus its global presence among the different areas of the city. Its very low level of integration makes it difficult to reach and access from the areas that are more inviting due to their configuration. Nevertheless, some of its premises are located in streets with strong potentials for movement.
Finally, Louvain-la-Neuve – exemplifying the ubiquitous precinct – shows values that are not among the highest, either for integration or choice, but which are consistent with a location in the most central areas of the system, paired with the occupation of a large area within the city. This means that the university premises form the average value of the system, since they are so deeply embedded in it. Their impact is vital. In these cases, the university is the most visible presence among the city’s various stakeholders, being the main promoter, a strong decision-maker, and responsible for creating many synergies and relationships.
UBIQUITOUS PRECINCT SYNTACTIC ANALYSIS

Figure 9 - Ubiquitous precinct syntactic analysis. Axial map source: Cannas da Silva (2017)

The segment analysis reinforces the results obtained in the axial analysis, namely:
In the case of the autonomous precinct – exemplified by Burnaby and Simon Fraser University – this increased the segregation of the university precinct and accentuated its low tendency for being crossed or used in random movements, because of its low potential for both to- and through-movement. Nevertheless, the university’s tendency to behave like a “city in a microcosm” (Turner 1984) appears justified in its internal structure, with a foreground and background network of its own when considering smaller radii of analysis.

Espoo – an example of the attached precinct or a campus bordering on the city – behaves differently because of the fragmentation of its fabric. The whole city presents the lowest values of mean NACH and NAIN, representative of a very weak background structure, and a very
fragmented fabric. In this case, the foreground structure becomes more relevant, being used for most journeys between different areas, since it assumes a very important connecting role between areas. Since the precinct is located in an area adjacent to the foreground network, it becomes more visible and likely to be visited during people’s travels. The precinct itself behaves as a background network and presents similar dimensions to many of the other fragmented sections of the urban territory, behaving as a unit within the fabric. The fact that the values of mean NACH and NAIN for the precinct are slightly higher than the ones observed when analysing the whole city, is a reflection of the structure of the precinct, as an urban unit that is not as weak as the average for the city.

MIT– an inner precinct – displays a similar situation, for opposite reasons. Despite its openness and its central location, close to the integration core, MIT presents an urban structure of its own, with a foreground network on the main campus axis, and a background network composing its inner territory. This dual structure, in the case of MIT, contributes to the success of the precinct. On the one hand, the importance of the main axes and their visibility within the system of the city of Cambridge make the university highly visible, turning it into an important element in the dynamics of the city, not only due to its location, but also because of the emphasis it places on opening its premises to the community and offering several activities and events for both the academic and the civil community. On the other hand, the seclusion of the inner areas of the precinct creates the isolation that is necessary for the development of some activities. In a very rational way, the precinct organises the more public uses in its most visible area, and the more private uses in its internal areas, which are characteristically difficult to navigate and less intelligible to outsiders. In contrast to the situation observed at Espoo, its inner structure does not behave as a background network because the system is fragmented or discontinuous. This is due to the configuration of its inner structure, designed to be fit for purpose.

The case of the city of New Haven – a developer precinct – shows the particularity of a university precinct that occupies the areas located in the integration core, while also simultaneously being a part of both the foreground and the background network. This urban behaviour can be extremely beneficial for the university, since it creates spaces with different characters which can be used for different purposes. The most visible area, with the highest through-movement potential, can be an important factor in promoting the university, making it highly visible to the outside community, and creating a sense of openness towards the city. The most secluded areas can be used for more private functions, such as laboratories and graduate schools and colleges. Considering that a university precinct of this type includes all the necessary living functions on its premises, it can also serve as a tool for urban regeneration, since it guarantees the presence of people in the city centre at all times of the day.

IST in the city of Lisbon represents the self-enclosed precinct. Despite its central location and its proximity to the integration core, IST has an isolated interior, completely separated from the highly integrated and highly visible axes around it. Like MIT, the precinct is rooted in the foreground network (but in this case due to its proximity relationship and not through its direct deployment) despite composing a background network with its inner structure. The precinct creates an urban unit within the city’s fabric. Its reclusive character is accentuated by its morphological traits, of which the wall marking out the limits of the precinct is the predominant feature.

Similarly, UCL, representing the open precinct, is also located in close proximity to the foreground structure, despite forming a strong background network with its precinct. The precinct behaves like a neighbourhood, with its unified and strong structure. Its openness, associated with its highly visible location, enhances the character that is defined by its spatial configuration, making it an area with a very high to- and through-movement potential.

The main difference between the precincts of MIT, IST and UCL is the strength of the background network that they are mostly composed of, which is a very strong structure in the case of UCL, but weaker in Lisbon and Cambridge. Furthermore, MIT is crossed by one of the main axes of the city of Cambridge, with high values in terms of integration, choice, NACH and NAIN, making it the precinct with the greatest potential for attracting movement both in the form of random movements and as a destination.
Bergamo – a scattered precinct – represents a different urban deployment of the university, not concentrating its premises in a clearly defined area, but rather disposing its buildings around the urban fabric. Such urban insertion can provide the university with greater visibility, or instead make its impact so diffuse that it lessens its importance. In Bergamo, due to the configuration of the city, where a strong sense of segregation is felt in the old upper area, the university suffers from a lack of visibility. Its buildings are located mostly in secluded areas, with very little potential for attracting to-movement, although displaying a slightly better behaviour when considering through-movement. This is a characteristic of the city of Bergamo, and not of the type of precinct, which can be very centrally located and present very high values of integration and choice.

Louvain-la-Neuve – a ubiquitous precinct – displays different characteristics. The city’s small dimension makes it structurally different from the other cases in the set. Despite the possibility of evaluating it with the use of the same tools, it would be important to analyse similar sections in each of the cities, in terms of their total number of segments, in order to fully understand the different behaviours of the university precincts within their immediate surroundings. The low values presented by the city in the segment analysis are coherent with its dimensions, but they still make it possible to understand the connection between the city and the university. These are intertwined, and the university occupies several locations within the urban fabric, having very similar configurations to those of the city, since the university composes the city and vice-versa, as was previously described in the axial analysis.

Some similarities can be observed between the different types of precincts, as far as the level of interdependence with the host city is concerned, as well as the level of the university’s inclusion within the urban fabric. Autonomous precincts and attached precincts present the lowest levels of interdependence with the host city, as well as a very low level of inclusion in the urban fabric. Nevertheless, it is still possible to distinguish between these, for the autonomous precinct presents lower values at both levels. Inner precincts present a similar level of interdependence with the host city to the one found in attached precincts, despite having a higher level of inclusion in the urban fabric, occupying areas that are fully encircled by this fabric. Self-enclosed precincts and open precincts present the same level of interdependence to and from the host city, despite occupying very different positions within the urban fabric. Despite the very central location of both types, the former present morphological features that afford them a severely isolated character, while the latter are completely incorporated into the urban fabric. Scattered precincts and developer precincts present both a very high level of interdependence to and from the host city, being slightly higher in the case of the developer precinct. Both present a very high level of inclusion in the urban fabric of their host city, being completely interwoven into it. Finally, ubiquitous precincts present the highest values, both in terms of their inclusion in the urban fabric and their interdependence with the host city.
5. CONCLUSION

Through the identification and characterisation of the different types of university precincts, there are some patterns that emerge in terms of their common features in relation to the host city. This provides us a deeper understanding of the levels of morphological integration that university precincts can achieve, which can have strong social and cultural consequences.

Most of the precincts analysed occupy areas within the most integrated half of the axes belonging to the system as a whole. The exceptions—autonomous precincts, attached precincts and inner precincts—tend to compensate for their low integration values with higher choice values, indicating that permeability is a valued feature sought by universities in establishing their precincts.

<table>
<thead>
<tr>
<th>Precinct Type</th>
<th>Autonomous Precinct</th>
<th>Attached Precinct</th>
<th>Inner Precinct</th>
<th>Developer Precinct</th>
<th>Self-Enclosed Precinct</th>
<th>Open Precinct</th>
<th>Scattered Precinct</th>
<th>Ubiquitous Precinct</th>
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<tbody>
<tr>
<td>Cases</td>
<td>Burnaby</td>
<td>Espoo</td>
<td>Cambridge</td>
<td>New Haven</td>
<td>Lisbon</td>
<td>London</td>
<td>Bergamo</td>
<td>Louvain-la-Neuve</td>
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<td>City Axial Lines</td>
<td>3941</td>
<td>6440</td>
<td>3479</td>
<td>2360</td>
<td>7858</td>
<td>15901</td>
<td>6027</td>
<td>1001</td>
</tr>
<tr>
<td>University Axial Lines</td>
<td>147</td>
<td>42</td>
<td>269</td>
<td>106</td>
<td>20</td>
<td>35</td>
<td>53</td>
<td>114</td>
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<tr>
<td>% of University Area</td>
<td>4%</td>
<td>0,7%</td>
<td>8%</td>
<td>4%</td>
<td>0,2%</td>
<td>0,2%</td>
<td>0,8%</td>
<td>11%</td>
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<td>City Segments</td>
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<td>8158</td>
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<td>21980</td>
<td>71155</td>
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<td>2407</td>
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<td>University Segments</td>
<td>230</td>
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<td>585</td>
<td>285</td>
<td>51</td>
<td>134</td>
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<td>288</td>
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<td>% of University Segments</td>
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<td>0,6%</td>
<td>7,2%</td>
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<td>University Mean Integration</td>
<td>1st quartile</td>
<td>3rd quartile</td>
<td>2nd quartile</td>
<td>4th quartile</td>
<td>4th quartile</td>
<td>4th quartile</td>
<td>2nd quartile</td>
<td>3rd quartile</td>
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<tr>
<td>University Mean Choice</td>
<td>0,911</td>
<td>0,603</td>
<td>0,892</td>
<td>0,82</td>
<td>0,867</td>
<td>0,753</td>
<td>0,839</td>
<td>0,727</td>
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<td>Mean Nach City</td>
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<td>0,741</td>
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<td>0,999</td>
<td>0,981</td>
<td>1</td>
<td>0,946</td>
<td>0,866</td>
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<td>1,509</td>
<td>1,564</td>
<td>1,594</td>
<td>1,581</td>
<td>1,667</td>
<td>1,478</td>
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<td>Max Nach Precinct</td>
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<td>1,594</td>
<td>1,262</td>
<td>1,506</td>
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<td>0,946</td>
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<td>0,693</td>
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<td>1,365</td>
<td>1,344</td>
<td>1,84</td>
<td>0,834</td>
<td>0,888</td>
</tr>
</tbody>
</table>

Table 1 - Syntactic analysis summary - university precinct types
Comparing inner precincts to self-enclosed and open precincts also provided some interesting insights. While the first of these tend to present low integration values, despite being completely embedded in the urban fabric, the others display soaring integration values. Nevertheless, their inner structures are very similar, mimicking the fabric of their host cities by assuming different characters in the more visible areas to the ones that are to be found in the deepest areas within their limits. Furthermore, self-enclosed precincts and open precincts present even more similar behaviours, being located in the integration core of their host cities. Scattered precincts presented very low values in terms of integration, but this might be a reflection of the structure of Bergamo as a host city, with the dichotomy between its old and new town, and the fragmentation and detachment of the two areas. Attached precincts and ubiquitous precincts present mean integration values above the average figure for their respective host cities. Finally, due to their location in the most central and visible areas of their host city, developer precincts also present extremely high integration values.

When choice is considered, attached precincts and inner precincts present the lowest values, but these are only slightly below the average of their respective host cities. Scattered precincts and ubiquitous precincts also present high choice values, above the average of the cities in which they are embedded. Finally, self-enclosed precincts, open precincts, and developer precincts present the highest values among the types analysed, being an indicator of a strong visibility of the university within its host city, in these cases.

There is a strong correlation between the nature and amount of the precinct’s boundaries and barriers, and the limits of its influence. The stronger the barriers and the definition of the boundaries encircling the precinct, the sharper the limits. In fact, strong impervious boundaries are perceived as an obstacle, not only limiting access to the university facilities, but also being perceived as creating a discontinuity in the urban fabric that can be damaging for the liveliness of the urban area in which the university is embedded. Furthermore, strongly closed boundaries project a University image quite opposite to its institutional "universal" nature. This aspect is highly visible when we compare the cases of University College, London (UCL) and Instituto Superior Técnico, Lisbon (IST). Despite the similarities in their locations within the urban fabric, both in terms of integration and choice, which would suggest that both precincts would behave similarly, the impact of IST’s surrounding non-permeable wall, completely changes the perception of the university territory in the adjacent areas. In the case of UCL, the precinct area behaves as an urban territory that is accessible and available to all, with the necessary exceptions in the interior of the buildings. At IST, despite its highly central location and the very high visibility of its precinct, its territory presents clear limits, so that it is not perceived as part of the urban realm.

Most of the university precincts assessed here are located in integrated areas of the city. However, a trend towards achieving a certain degree of seclusion is observed, protecting the academic environment from the city. This trend may be materialised in the form of different features, ranging from the syntactic properties to the presence of physical barriers and boundaries. Even in the cases where the precinct is located in highly visible and accessible areas, intelligibility within its premises can be used to enhance privacy in certain areas.

In a context in which this tendency is gradually reverting to a posture of openness towards the urban environment that fosters the creation of links and connections, bridging the “academic divide”, space syntax tools provide valuable insights into key aspects, such as the need to enhance visibility and improve integration.

This paper attempts to identify patterns of university precincts location considering their hosting cities. It considers eight precinct genotypes, morphologically different. Despite the evidence suggesting different genotypes present different location characteristics, as well as different configurational properties, materialized in different behaviours towards the hosting city, the sample is too small to allow for a generalization. However, space syntax tools and methodologies seem promising in assessing, characterizing and understanding the urban behaviour of universities, thus allowing to inform and predict possible connections and relationships between the university precinct and its urban surroundings.
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ABSTRACT
What are the drivers of urban transformation, including microeconomic diversity and growth? And what could refrain transformation? The city of Rio de Janeiro received 218 developments of the Brazilian Public Housing Programme “Minha Casa Minha Vida” (PMCMV) in the last five years, mostly located in peripheral areas. Recurring criticism has been made to the programme in relation to size and locations of projects, along with a lack of urban diversity and infrastructure. Verifying the assumptions latent in such criticism, this paper develops a methodology to assess (1) the degree of microeconomic support that the built environment offers to residents; (2) the morphological and functional interfaces of new housing complexes and their neighbourhood; and (3) the impacts these complexes have on the economic diversity of their surroundings. In a first empirical study, social and spatial attributes of areas around twelve housing complex in areas of different levels of topological accessibility and building density were compared, including pedestrian movement, distribution of retail and services, and an index of diversity in urban activities based on Shannon’s entropy. A second empirical study analyses variations in land use and land parcelling in West Rio, from 2011 to 2015. Assessing the impact of housing complexes on the microeconomic diversity, this approach identifies divergences between patterns of accessibility, and patterns of location of housing compounds and activities. Results indicate (i) substantial differences in topological and absolute distances to the CBD; (ii) strong influences of accessibility in the morphological and microeconomic integration between housing complexes and their neighbourhoods; and (iii) significant influence of land subdivision on the rate of change of land uses in areas of sprawl.

KEYWORDS
Diversity, microeconomy, sprawl, land subdivision.

1. INTRODUCTION
What are the drivers of urban transformation and microeconomic diversity? A long tradition in spatial economics and more recently in space syntax tell us that accessibility, assessed either as absolute or topological distances, is a key, axiomatic factor. From Von Thünen’s rural economics to Hansen’s (1959) “How accessibility shapes land use”, Alonso’s (1964) general theory of land rent, and Goffette-Nagot’s (2000) “Urban spread beyond the city edge” on the one hand, and Hillier at al’s (1993) “configuration and attraction in urban pedestrian movement” or Chiaradia et al’s (2013) “compositional and urban form effects on residential property value patterns” on the other, we came to understand the central role of accessibility both in concrete, visible
change in three-dimensional form, and in hidden or elusive things like land values, land uses and pedestrian movement. But there might be other vectors of growth and transformation. For instance, what are the impacts of top-down decisions on new, large residential complexes? Do massive public housing compounds qualify as such vectors? On the other hand, what could refrain transformation? Economists tell us about disadvantages of agglomeration such as city size, traffic congestion, air pollution and so on. Here we could well include poor accessibility and progressive urban sprawl.

In this paper, we analyse urban phenomena that seems to fit such patterns of stimulus and hampering to transformation – namely, the effects of top-down housing decisions under certain conditions of accessibility and (topological and absolute) distance on the local diversity of activities. By looking into cases of housing complexes in areas of urban expansion in Rio, with low density and poor transportation facilities (we should say 'sprawl!'), we could observe rapid local transformations in urban diversity – and found empirical traces of something previously little explored: how the ‘infrastructure’ of architectural morphology, namely the plots that define property and parcels of land to build, takes part in the dynamics of transformation – a potential role for the virtually invisible ‘legal frame’ of morphology, or what we call ‘the hidden morphology of plots’.

Recent work carried within the syntactic community (Netto et al, 2012; Netto, 2017; cf. Al-Sayed & Penn, 2016) has shown that the process of convergence of urban patterns such as accessibility, density and land uses, mostly assumed in spatial economics and space syntax, is far from unproblematic. It is subject to processes of progressive diffusion stemming from collective action into other dimensions of the urban, taking the form of passages and mutual influences. It seems mediated by information, i.e. by how actors learn about spatial advantages in accessibility and land values. It may also be influenced by fluctuations of land values potentially dependent on micro and macro economies; by changing densities and processes of building substitution; and by changes in accessibility itself. However, these previous works have not brought to the forefront the potential role of the ‘hidden morphology of plots’ as a material layer mediating urban transformation.

The idea is simple: certain plot structures (especially regarding size) may either ease or refrain change in land uses and the substitution of buildings or the densification of urban form. We use as a case in point the impacts of public housing complexes built by the gigantic federal programme “Minha Casa Minha Vida” (PMCMV) in the city of Rio de Janeiro. Between 2011 and 2015, Rio had received 218 developments from the public housing Programme “Minha Casa Minha Vida” (PMCMV). Of this total, 148 complexes or 68% are located in the western area of the city. West Rio is the most recent area of expansion, displaying low density and brownfield land along with industrial and rural activities. Its expansion began in the 1950s and was further developed in the 1990s. There is a remarkable lack of efficient infrastructure and public services, such as transport and health and education facilities.

Unsurprisingly, the construction of these complexes has generated strong critical reactions, mainly concentrated on problems with extremely large distances from Rio’s Central Business district (CBD) and other job locations, and on the surroundings of housing complexes, which tend to display a poor capacity to meet the daily demands of residents, causing them to travel long distances. The typological difference of the dwellings can also be considered as an impact factor. Small plots of single-family residence of up to two floors predominate in this region. However, housing projects under the Programme “Minha Casa Minha Vida” are usually built in the form of very large gated communities with multi-storey typologies.

Verifying the assumptions latent in these critical views, this article proposes a new methodology to evaluate (i) the degree of microeconomic support that the built environment offers to local residents; (ii) the morphological and functional interfaces of new housing complexes and their neighbourhood; and (iii) the impacts that these complexes have on pedestrian movement and the microeconomic diversity of their surroundings. The approach first analyses the diversity of microeconomic activities around twelve housing complexes using an index derived from Shannon’s (1948) information entropy. Secondly, social and spatial attributes of the areas around
each housing complex are compared, including pedestrian movement, retail distribution and service, and an index of activity diversity, morphological characteristics and spatial accessibility. In a third moment the research analyses the variation of land uses and the potential influence of the land parcelling in an area of expansion of the West Zone, creating a temporal analysis of microeconomic activities before and after the construction of the housing complexes. Our data indicate that the new gated communities have effects as vectors for transformation of these areas, namely toward increases of microeconomic diversity.

Assessing the impact of the complexes on the density and diversity of their surroundings, we shall see that the streets where the housing complexes are located tend to be the highest accessibility and density levels, while the streets where microeconomic activities are emerging tend to be streets with lower accessibility levels. This counterintuitive condition seems to imply a break in one of the axioms of spatial theories such as urban economics and space syntax alike, according to which variables like density, accessibility and activities location tend to converge. This unexpected empirical finding prompts the need for further explanations, which might reside either on contingent and contextual conditions that often elude theory, or on generalizable phenomena perhaps underestimated in classic approaches – although complexities in the relationship of street accessibility, location factors, land-use diversity and land values have been identified (e.g. Shen and Karimi, 2016; 2017). Assessing the problem inductively, our morphological analyses will suggest that the actual structure and size of urban plots may be preventing the establishment of new activities in streets with the highest accessibility levels, leading to biases or negative implications over potential multiplier effects generated by accessibility and microeconomic forces.

Results indicate (1) substantial differences in the performance of housing complexes regarding degrees of integration and distance to the city centre; (2) strong influence of accessibility and site layout as morphological and functional integrating factors between housing complex and neighbourhood, including evidence of negative impacts on connectivity and grid intensification, increased presence of walls, and monofunctionality; (3) potential influence of the structure of land subdivision on the rate of change of land uses in areas of potential urban growth.

2. SUPPORT FROM THE NEIGHBOURHOOD: MICROECONOMIC DIVERSITY

The Brazilian Federal Government launched the Minha Casa Minha Vida Programme in 2009 with the main goals of expanding the access opportunities of low-income families to homeownership, and reducing a historic, massive housing deficit in the country. The programme categorises beneficiaries into three bands of monthly income: up to USD $669.46 (band 1), up to $1297.07 (band 2) and up to $2092.05 (band 3). Nevertheless, Programme and the design of housing complexes have been subject to relentless criticism by experts. Location is a first major issue, and Rio de Janeiro offers a paradigmatic case in that sense. With on-going expansion, West Rio has many areas without adequate infrastructure to support the population, whether they are services provided by the State, such as health, education and public transportation, whether daily activities to support residents, such as commerce and services.

Previous works identified a common practice among developers: to buy large chunks of peripheral land and divide them into several smaller pieces, which are then contracted separately as individual, similar projects (Cardoso and Lago, 2015). These pieces end up functioning morphologically as one large housing complex. It was identified that 71.86% of the housing complexes in the metropolitan area of Rio de Janeiro meet this criterion (Cardoso and Jaenisch, 2014). Rio has received more than 61 thousand housing units. 71% of the housing units are located in West Rio (figure 1). These data reinforce the 2010 Census information (IBGE, 2014), which confirmed that Rio de Janeiro is still in the process of expanding to the west, a process that has been taking place since the 1950s. These large-scale collections of developments, usually made up of complexes with more than 200 housing units, are also said to have impacts on their neighbourhood, considerably increasing the local demand for services and retail.
Due to temporal and logistical reasons, we selected twelve out of 218 projects contracted in 2015 (from which only 63 projects were built by then). Our criteria involved four major issues in the research problem: (a) **architectural typology** (namely, the two most frequent types: H-shaped towers, and slabs); (b) **income levels** attributed to selected cases by the Programme itself (the number of cases per income level is proportional to the overall distribution of complexes per income level in Rio); (c) **location** (according with two main location areas preferred by the Programme, North and West zones); (d) **number of housing units and buildings** per complex (we only considered cases in the second and third quartile of the histogram of distribution of units in the complexes, discarding both the largest and the smaller complexes (25% of the upper end and lower end of the histogram) (figure 2).

In order to verify the arguments of previous critiques to location of the projects, we devised an approach to measure the degree of microeconomic diversity of the environment to support residents, based on surveying land uses within 5 minutes walking distance from the entrance of the housing complexes (radius of 460m - figure 3).
The activities of these areas were classified in two ways: first, in four classic categories from the point of view of urban planning: residential, services, retail and institutional uses. The second one was based on more detailed categories derived from the National Classification of Economic Activities (CNAE), with activities aggregated into 24 categories with sense from the point of view of urban economics (table 1).

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>1. Residential</th>
<th>2. Food and beverage (markets, sales, no local consumption)</th>
<th>3. Car repair and auto parts</th>
<th>4. Gas station</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5. Construction material (blacksmithing, carpentry)</td>
<td>6. Household goods</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7. Pharmaceutical products, perfumes, cosmetics</td>
<td>8. Clothing, footwear, jewels</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9. Liquefied petroleum gas (LPG - cooking gas)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>10. Informal retail</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>11. Hotels and similar</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>12. Restaurants and other food and beverage services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13. Street-vended foods</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14. Professional, technical and scientific activities</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>15. Administrative activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16. Public administration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17. Education</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>18. Human health and social services</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19. Arts, culture, sports and recreation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20. Transportation and storage (parking lots, warehouse and storage areas)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21. Information and communication activities</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>22. Financial and insurance activities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>23. Church and other associations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24. Other activities and services</td>
<td></td>
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</tbody>
</table>

Table 1 - Categories of urban activities used in the analysis of diversity. Source: Authors / CNAE.
The degree of diversity of activities was based on the information entropy formula proposed by Shannon (1948). Diversity is a measure of distribution: a perfectly homogenous distribution of activities along a given number of categories finds maximum diversity. If activities are concentrated in a single category, diversity is non-existent. The measure takes into account the number of activities (land uses) in relation to the total number of activity categories, and varies from zero to 1. Empty plots were considered in the proportion of activities in analysed areas, but excluded from calculation, as they do not represent a microeconomic activity. The degree of diversity was analysed in 10 surrounding areas of 12 housing complexes in a comparative study between complexes of different zones.

\[
E_i = - \frac{\sum_{j=1}^{k} (P_{ji})(\ln P_{ji})}{\ln k}
\]

\(E_i\) = entropy index in sector \(i\)
\(P_{ji}\) = parcel occupied by activity \(j\) in sector \(i\) or proportion of units with activity \(j\)
\(k\) = number of categories of activities considered (land use)
\(\ln\) = natural logarithm

Then we could test some axioms of urban economics: the relation between urban diversity, density and distance. Our empirical study also included variables like commuting time to the central business district and density according to 2010 Census data (table 2).

<table>
<thead>
<tr>
<th>Housing complex</th>
<th>Distance CBD (km)</th>
<th>Density Hab/ha</th>
<th>Diversity 24 categories</th>
<th>Diversity 4 categories</th>
<th>Integration (R_n)</th>
<th>Integration (R_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>16.0</td>
<td>108</td>
<td>0.4</td>
<td>0.61</td>
<td>0.36</td>
<td>2106705.19</td>
</tr>
<tr>
<td>19</td>
<td>13.2</td>
<td>233</td>
<td>0.4</td>
<td>0.71</td>
<td>0.4</td>
<td>1474754.47</td>
</tr>
<tr>
<td>20</td>
<td>13.2</td>
<td>233</td>
<td>0.4</td>
<td>0.71</td>
<td>0.34</td>
<td>1474754.47</td>
</tr>
<tr>
<td>23</td>
<td>43.8</td>
<td>34</td>
<td>0.31</td>
<td>0.47</td>
<td>0.25</td>
<td>1700813.76</td>
</tr>
<tr>
<td>27</td>
<td>17.0</td>
<td>119</td>
<td>0.5</td>
<td>0.68</td>
<td>0.33</td>
<td>1443623.76</td>
</tr>
<tr>
<td>30</td>
<td>38.5</td>
<td>27</td>
<td>0.3</td>
<td>0.44</td>
<td>0.30</td>
<td>1507468.53</td>
</tr>
<tr>
<td>37</td>
<td>46.0</td>
<td>34</td>
<td>0.25</td>
<td>0.52</td>
<td>0.27</td>
<td>1815151.82</td>
</tr>
<tr>
<td>39</td>
<td>44.7</td>
<td>27</td>
<td>0.18</td>
<td>0.27</td>
<td>0.28</td>
<td>1221199.56</td>
</tr>
<tr>
<td>42</td>
<td>38.0</td>
<td>27</td>
<td>0.21</td>
<td>0.28</td>
<td>0.29</td>
<td>1012758.63</td>
</tr>
<tr>
<td>48</td>
<td>11.2</td>
<td>116</td>
<td>0.56</td>
<td>0.71</td>
<td>0.34</td>
<td>1492244.86</td>
</tr>
<tr>
<td>62</td>
<td>57.3</td>
<td>17</td>
<td>0.28</td>
<td>0.41</td>
<td>0.31</td>
<td>2261443.41</td>
</tr>
<tr>
<td>63</td>
<td>57.3</td>
<td>17</td>
<td>0.28</td>
<td>0.41</td>
<td>0.31</td>
<td>2261443.41</td>
</tr>
</tbody>
</table>

Table 2 - Distance and commuting times to CBD, local density and diversity.

Analysing the convergence levels between distance, population density and diversity of microeconomic activities pointed out by studies in urban economics, we have found some high statistical correlations (table 3): the greater the absolute distance to CBD, the lower the density (-0.85); a strong positive correlation of diversity and density considering four categories of activity (0.83) and 24 categories (0.64); along with strong negative correlations of diversity and absolute distance (-0.82 for four categories, -0.80 for 24 categories). Topological accessibility follows these trends, with strong positive correlations of integration \(R_n\) (average for street segments within a 460 radius around housing complexes entrance), density and measures of topological accessibility.

1 Correlations based on the Pearson coefficient range from zero to -1 or +1 (perfect negative or positive correlation). The statistical significance test (p-value) examines the probability of an observed result if it repeats or arises by mere coincidence. P values equal to or greater than 0.05 are not statistically significant, according to the conventionally adopted parameter of 95% confidence.
diversity. Correlations of absolute distance and global integration find empirical sense (0.70), whereas correlations of integration R3 and distance, density and diversity have found no statistical significance.

<table>
<thead>
<tr>
<th>Correlation Matrix: Pearson</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td>Distance CBD (km)</td>
</tr>
<tr>
<td>Density (Hab/ha)</td>
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<tr>
<td>Diversity 24 categories</td>
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<tr>
<td>Diversity 4 categories</td>
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<td>27</td>
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<td>30</td>
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<td>48</td>
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<tr>
<td>62</td>
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<tr>
<td>63</td>
</tr>
</tbody>
</table>

Table 3 - Correlations of absolute distance and CBD, integration (Rn), local density and diversity. P-values < 0.01 except * (< 0.05).

However, complexities and divergences in this relationship become more evident when we plot the distance of housing developments to the CBD in relation to the diversity level of microeconomic activities (figure 3). We can see that diversity falls, especially from 16 km away from the CBD, from a trend of 0.40 to 0.20, with variations up to 0.30, considering the 24 categories in the 460-meter radius from each housing complex (figure 4).

Figure 4 - Diversity (Y axis) and distance to CBD (X axis).
The numbers confirm to some extend the axiom in economics since Alonso’s (1964) monocentric model: the further away from the centre, the lower the diversity of activities around housing complexes. But there is no linear decay of diversity along with the increase of distance. This indicates complexities such as potential local centralities (e.g. polycentric structures, captured in Zhong et al, 2015 and Shen and Karimi, 2016) and divergences between land use distributions, accessibility levels, and distance (Netto et al, 2012; Netto, 2017).

One of the consequences that the low diversity of activities have for residents of is the greater need of movement around the city in search of retail and public services, like access to health and education. These data confirm previous critiques made to the programme regarding location and areas with little supply and diversity of services to support the daily activities of residents, especially considering diversity levels found in consolidated areas such as Copacabana and Ipanema (0.82 and 0.71, respectively).

3. INTERFACES OF HOUSING COMPLEXES AND NEIGHBOURHOOD

Considering that accessibility relates to the connectivity of the grid and that this is a factor of attraction, increasing the possibility of connections with the city also tends to increase the possibility of access to commerce and services. We also know that the street network directly relates to land uses and architectural densities that will be added to it – factors at once combined in the generation of multiplier effects on pedestrian movement (cf. Hillier et al, 1993) and dependent on it. We also know that each of these urban patterns (land use and pedestrians) involve different temporalities of production: street networks change in the course of centuries, architectural densities and land use patterns may emerge and become stable for decades, while pedestrian movement is the most volatile of these systems and may change rapidly according to contingencies (Netto et al, 2012; Netto, 2017).
Figure 6 - Location, neighbourhood and aerial view the public housing complexes 27, 30, 37 e 39.

Figure 7 - Location, neighbourhood and aerial view the public housing complexes 42, 48, 62 e 63.
In order to analyse the functional relationship between new housing complexes and neighbourhood (figures 5-7), we analysed street segments within a radius of 460m from housing complexes, measured their levels of accessibility (global and local integration), morphological features (number of plots, type of plot interface or the relationship of façade and public space mediated by fences, walls or open plots) and assessed levels of pedestrian movement.

Regarding accessibility, there is a correlation of -0.31 (p-value 0.06) between local integration and segment length. This indicates that the highest accessibility rates are more likely to be found in shorter streets. Local integration finds a positive correlation with open plots (0.51 | p-value < 0.01), that is, there is a tendency of segments with higher accessibility rates having more open plots than walls. Open plots also find a positive correlation with pedestrian movement (0.38 | p-value < 0.05)

In turn, correlation between microeconomic diversity (activities on the ground floor) and open plots suggests a positive association (0.37 | p-value < 0.05). Accessibility continues to show its strength when we analyse its correlation with pedestrian movement (0.42 | p-value < 0.01), indicating that streets with greater local integration and open plots tend to have a more intense pedestrian movement.

Summing up, correlations suggest multiplier effects between accessibility and morphological features, where streets with greater accessibility try to attract plots that connect with open façades, allowing a greater diversity of microeconomic activities that in turn attract more pedestrians (cf. Narvaez et al. 2012; 2016). When large housing complexes are built in streets with high accessibility but surrounded by walls and exclusive residential activities, they become large enclaves in the neighbourhood, not allowing a direct interface of dwelling and street, preventing changes of land use and directly impacting pedestrian movement.

4. IMPACTS OF HOUSING COMPLEXES ON LOCAL ECONOMIC DIVERSITY

Another key problem analysed regards possible consequences of the construction of the housing complexes, where new gated communities located in areas of low density could become vectors of transformation of the microeconomy in their neighbourhood. Considering a dynamic scenario, transformations including increases in the diversity of activities could happen over time. Any potential increase in diversity would meet the needs of these new residents in a circular cumulative effect a la Myrdal (1957), where new residents would generate demand, and microeconomic diversity would increase, stimulating new demands (figure 8).

Figure 8 - Dynamics of the influence of residential complexes on the diversity of the environment.
In order to analyse the microeconomic impact of the housing complexes in their surroundings, a comparative study was carried out focusing on the degree of diversity before and after construction (figure 9). We analysed an area of 3.15 km² around 11 projects in Campo Grande (West Rio), which total 3753 housing units and approximately twelve thousand new residents, between 2011 and 2015.

Figures indicate an increase of 118% of households and a 121% increase of residents in the analysed area, representing a significant growth of density in a five years period (table 4). Further data were collected through field surveys and analysed according to density, land use, activity and microeconomic diversity.
We have found a growing presence in all types of activities in this area since housing complexes were built. We highlight the great increase of services (growth of 95%), while the retail in the area had a growth of 36%. This difference can be explained by the trend of concentration of commercial activities in large hypermarkets and shopping malls, and services tend to be dispersed in small units, each one within its specialty (Almeida, 1997).

This intensification of activity is also perceived in the degree of diversity, the diversity level was 0.282 in 2011 for four categories, increasing to 0.318 in 2015. In turn, our analysis for 24 categories of economic activities based on the National Classification of Economic Activities (CNAE) (see table 2), which captures variations with more precision, shows a diversity level of 0.381 in 2011, and 0.445 in 2015 (table 5).

Table 4 - Variation in land uses in plots of Campo Grande, West Rio (2011-2015).

Table 5 - Evolution of microeconomic diversity in Campo Grande, West Rio.

So there is a substantial increase in the diversity of the microeconomic activities along with increases in the number of activities and population density. The arrival of the twelve thousand residents of the Minha Casa Minha Vida projects creates a mass of new final consumers, increasing demand and the presence of suppliers. The location of microeconomic activities can be explained by their pursuit of the consumer market – and here space matters, as the attractiveness of the market depends on the size of its clientele (Fujita and Thisse, 1996). A larger consumer market generates centripetal force capable of attracting retail and services to the area, while reducing transportation costs and daily efforts. The relationship between density and diversity found empirically therefore confirms one of the axioms of spatial economics: a strong association, mutual stimulus and positive externalities between these urban patterns (Jacobs, 1969; Glaeser, 1992; Henderson, 2002).

5. MEDIATING THE TRANSITION FROM ‘DEMAND’ TO ‘LOCATION’: THE HIDDEN MORPHOLOGY OF PLOTS

Of course we are looking here only at the ‘tip’ of the economy, as final suppliers involved in retail and services, and final consumers – the last stage of long cycles of production and intermediary exchanges. We are finally in a position to assess the role of urban structure in the transition from the social and microeconomic demands of residents to the way suppliers are able to materialise their activities into new locations in an area, changing land uses and density patterns along the way. We know that accessibility and density have roles in the change of diversity – but is there more to this? What are the contingencies at play? Are there more active structural features, perhaps underestimated in classic urban and microeconomic approaches?

Our examination of land use changes in West Rio led us to a curious observation. We noticed that the ‘infrastructure’ of architectural morphology, namely the plots that define parcels of
property, seem to take part in the actual process of urban transformation, allowing changes to emerge or slowing them down. This suggests a possible induction: the possibility that plot structures (especially regarding size) may either ease or refrain change in land uses and the densification of urban form.

Recent research has shown that the process of convergence of patterns such as accessibility, density and land uses is in fact quite problematic. Changes in the realm of collective actions (e.g. new residents with new consumption needs) have to be read by other actors (suppliers). Suppliers have to find now local spatial opportunities in order to meet the new demand. All these actors have to learn about spatial advantages such as the best accessibility levels and favourable land values. New tenants have to be installed, buildings built or adapted, so that land uses can change. This is a process mediated by information diffusion, an economy, and different materialities (in practices and in spaces) and temporalities (in demand, creation of new activities, transformation of actual spaces and buildings) at play. It is a complex, challenging process – and one that goes virtually unnoticed. We suggest that the ‘hidden morphology of plots’ is one of the material layers mediating it.

Let us see our case in point. Maps indicating changes in land uses (figure 5) show that microeconomic activities and diversity is concentrated in streets where the of plots are the small plots facing directly onto the street, are the dominant type. In their turn, large plots used for the housing projects have architectural models that do now allow spatial change. These models freeze any possibility of change expressing microeconomic potentials around them. Most of other large-scale plots also keep their previous land use and continue stable as a pattern, as their land values and size require larger, more complex investment. A particular, small plot size shows higher change rates in their land uses. This indicates that the size of the plots might have a role in the speed of changes in land uses. Of course a single observation can only suggest possibilities of research and offer new hypotheses to be tested, namely around the role of land parcelling as part of the condition and rate of diversification of activities in an urban area.

6. SOME FINAL OBSERVATIONS

Traces of the impacts of housing complexes in their surroundings empirically collected in Rio de Janeiro suggest that these large-scale programmes can actually become relevant vectors in urban dynamics and transformation, given that their location have potentially extraordinary implications in local economic action. However, what can be perceived is that this microeconomic impact is reflected in a consolidated mesh and with small plots that allow the change of use, which the ventures in the form of condominiums do not allow. The rapid changes observed suggest a tremendous interactivity between urban subsystems, as the location of new residential complexes even in distant, low-density areas with fragmented street networks find new relations in intensifying microeconomic activities and diversity.

Our approach also allow us to reassess arguments typical in the criticism regarding the location of housing complexes and the practical support to be found in their areas. Distance, density and diversity are problems felt by new residents. In time, residents themselves become agents of self-organisation, minimising initial problems. Other findings indicate the following:

- There are substantial differences in the performance of different locations as far as accessibility and spatial segregation is concerned, which correspond to differences in diversity, interesting from the point of view of residents.
- There are potential implications between the interfaces of housing complexes and their neighbourhoods and pedestrian movement. The model of walled, gated communities replicated ad infinitum by developers and their negative impacts on the connectivity of street system seems harmful to the vitality of the environments where they are built.
- We found signs of a possible influence of land subdivision on the rate of change in land uses in areas of dispersed expansion, directly affecting housing complexes and their surroundings, which seem to deserve more theoretical and empirical attention.
Negative factors can be minimized through urban planning policies and more rigorous regulations regarding the scale of projects, possibilities of mixed use, and avoidance of gated communities (at least bordering one another) – in addition to studies of location and impacts within neighbourhoods.
REFERENCES


ABSTRACT

Safety is one of the most important conditions for pedestrian activity and a principle that should underpin any public realm scheme. However, there is still a gap in understanding where collisions and pedestrian casualties happen and thus, a lack of tools to be applied from the urban design discipline to prevent them. Our initial hypothesis is implicit in pedestrian safety guidelines: collisions take place where there is an imbalance between high pedestrian demand (pedestrian desire lines\(^1\)) and low public realm quality. This statement has the potential to be analysed systematically and as a prevention tool.

This paper presents the case study of Peckham Town Centre, London. Peckham Town Centre was selected as part of a Transport for London (TfL) initiative to develop transport strategies with the objective of improving pedestrian safety, promote walking and to improve the overall pedestrian experience in town centres.

Pedestrian desire lines were identified using the space syntax methodology, which has proven its capacity in understanding pedestrian route choices and flows through streets network configurational analysis. In a consistent way, Visibility Graphic Analysis (VGA) of spatial configuration added to land use data offered a detailed, weighted description of pedestrian route choices. Public realm quality was assessed using PERS (Pedestrian Environment Review System). The identification of ‘unsatisfied desire lines’, i.e., pedestrian routes which as not supported by good, adequate design, was subsequently compared to the collision data from 2011 to 2015.

The analysis found that there was a strong correspondence between spatial morphology and the location of collisions. Surprisingly, the analysis showed little correspondence between the quality of the public realm and collision locations. Lastly, the study tested the methodology applicability to development options without compromising on urban vitality, public space connectivity or community severance.

KEYWORDS

Collision, Pedestrian safety, Space syntax methodology, Urban morphology, Visibility Graph Analysis (VGA)

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\(^1\) Pedestrian desire line is defined as the preferred route a person will take to travel from A to B. Often, this is the most direct and quickest route someone can take and does not necessarily follows a ‘designated path’. Parks are a clear example where visitors walk across the grass, rather than using the available paths, when those paths are not aligned with the most direct, simplest route between locations.
1. INTRODUCTION

Safety is one of the most important prerequisites for pedestrian movement in the urban environment and, thus, should be considered at the heart of any public realm scheme or masterplan. Pedestrian safety is also a matter of public health: only in Greater London, between 5,000 and 6,000 pedestrians are involved in a collision annually, of which nearly one hundred lose their lives (Transport for London, 2016). Pedestrian safety should also be safeguarded as part of all strategies seeking to encourage active, sustainable travel. Pedestrians are the most vulnerable group when looking at overall road safety: also in London, despite being involved only in 18% of all collisions, pedestrians accounted for nearly half (49%) of the fatalities (Transport for London, 2016).

It is the responsibility of planners, designers, engineers and architects to plan and design safe environments. However, there is a general lack of methodologies to assess the degree of safety that a plan or design provides, prior to its implementation and to any collision events. Another challenge is the need of applying methods to analyse urban environments at a very micro-scale, given that some studies have pointed to the important role of some micro-scale factors, such as the location of crossings, bus stops or retail units in the incidence of collisions.

Our study exams two cutting-edge methodologies – Visibility Graph Analysis (VGA), carried out using the Fathom software developed by Atkins Ltd, and Pedestrian Environment Review (PERS) – to understand the correspondence between urban environment variables and the location of collisions at the micro-scale of urban areas. These two methodologies correspond to two levels of practice: VGA analyses urban form, the impact of land use distribution and the location of transport services. These factors relate to the level of master planning and generally are not easily modifiable. In contrast, PERS addresses the perceived quality of physical elements such as the width of footways or crossings, which belong to the micro design level and are easier to modify. These two methodologies structure our study.

1.1 STATE OF THE ART: WHERE COLLISIONS HAPPEN OR WHERE PEDESTRIANS GO

Common pedestrian safety strategies to date have paid attention to both pedestrian and driver behavioural change through education, encouragement and law enforcement on the one hand, and innovations in road design, engineering and traffic calming strategies on the other hand. These strategies have been supported by studies of the influence of certain factors on collision risk, such as pedestrian characteristics, i.e., age, gender or ability or vehicle speed (Zegeer & Bushell, 2012). However, the environmental and contextual factors associated with the location of collisions involving pedestrians have been generally less studied (Moudon et al., 2008).

Pedestrian safety strategies have incorporated some urban environment issues, such as road design, lighting, maintenance, speed limits or specific equipment such as safety cameras, crash-protective objects or countdown traffic lights (Transport for London, 2013). These can be framed into the field of public realm design and, therefore, can be easily modified in a ‘quick-win’ street re-design project.

Yet, Moudon et al. (2008) and Shawky et al. (2014) highlight that several factors, such as the crossing typology, have limited effectiveness to promote safety. In contrast, they suggest that the highest risk of collisions take place in areas where the concentration of retail activities takes place. However, as Moudon et al. argue, retail concentration might be just a proxy measure for pedestrian activity in a given area.

This statement leads the discussion towards a different approach: should we rather focus on the factors influencing pedestrian movement? The literature has identified consistent evidence pointing at urban morphology and land use distribution as the main drivers of pedestrian activity, strongly correlated with pedestrian counts.
Based on network analysis, Space Syntax methodology (Hillier & Hanson, 1989; Hillier et al., 1993; Hillier, 2007) analyses the street network from a configurational perspective. Space syntax variables, such as choice or integration, highly correlate with pedestrian flow volumes and distribution. These variables summarise relevant topologic and geometric patterns and develop the idea of natural movement and wayfinding due to visual connections. This methodology has succeeded in identifying the pedestrian ‘desire lines’ of movement, mapping the places with a higher pedestrian demand and the most common pedestrian itineraries.

Within the same theoretical basis, Visibility Graph Analysis (VGA) allows the assessment of urban spaces at a more micro level (Turner et al., 2001; Desyllas & Duxbury, 2001; Turner, 2003). Space syntax representations such as axial lines (straight parts of the street network) and, later, street segments between two consecutive junctions (Hillier et al., 2010) provide a ‘large’ scale representation and quantification of urban spaces. In contrast, VGA enables a finer granularity and the analysis of different locations within the same street segment, with a distinction between footways, if required. This level of detail results in improved correlation coefficients with pedestrian flows (Desyllas & Duxbury, 2002).

Including land use data and transport node locations into the analysis have the potential to improve the correlation even further (Desyllas et al., 2003). This seems evident as land use density, commercial activities and public transport nodes are clear pedestrian trip generators, even though their contribution to the correlation may not be as crucial as expected (Ozbil et al., 2011). However, regardless of its overall contribution to pedestrian collision risk, consistent studies suggest the importance of land use variables, such as population and employment density (LaScala et al., 2000; Graham & Glaister, 2003), besides the concentration of retail activities introduced before.

1.2 RESEARCH QUESTIONS AND GOALS

The literature points at urban morphology, street network topology and geometry, land use distribution and density as variables that explain pedestrian volumes in the urban environment and thus the pedestrian exposure to collision risks. However, most pedestrian safety strategies deal with the urban environment at the micro level of design.

The goal of this study is hence to re-frame the subject of pedestrian collision location according to these two levels of spatial intervention: micro design versus urban form including land use. We, therefore, ask ourselves the following questions: What is the role of design quality in enhancing pedestrian safety? Are current pedestrian safety strategies right at focusing their action at the scale of the road and public realm design? Would a double approach (urban planning vs. design) support a stronger understanding of collision locational patterns? To that end, this study compares these two scales of interventions to inform, redefine or consolidate pedestrian safety strategies.

Opposing urban form and design quality leads to four space types: ‘Successful pedestrian spaces’ (high demand, good design quality), ‘unsatisfied-desire lines’ (high demand, poor design), ‘back forgotten spaces’ (low demand, poor design) and ‘red-carpeted deserts’ (low demand, good design), whereas demand relates to pedestrian flow volumes and design refers to the physical elements constituting the public realm’ (Figure 1). All variables are analysed at the micro level of the collision location, which is also the micro level of intervention for some elements, e.g. crossings or pavements.

2 There are a range of factors that can be used to assess the design and quality of the public realm. In this study, we based our criteria on the PERS methodology (refer to Section 2.3) including suitable materials, accessibility (gradient and dropped kerbs), lack of clutter, lighting, maintenance and quality of environment. We did also consider adequate footway width in line with Transport for London guidelines (2010). This does not exclude other important design elements such as street furniture, greenery, distinctive character and desirability.
However, the urban form variables are the consequence of urban planning decisions at a more macro scale of intervention, such as the scale of a masterplan. The four fundamental typologies used to frame the topic and discussion are summarised in the Space-Type Diagram below:

A first thought would be that pedestrian collisions are most likely to happen on ‘unsatisfied-desire lines’, where there is a high pedestrian demand in areas of poor design quality. Following the same reasoning, if design plays a crucial role in safety, one could assume that those places with high design standards are overall very safe, regardless of the level of pedestrian activity hosted. Likewise, one should not expect many collisions where pedestrian demand and exposure are very low.

Pedestrian safety strategies seem to accept the implicit assumption that collisions are indeed most likely to take place on ‘unsatisfied-desire lines’ type of locations. This study however sheds light to this assumption.

2. DATASETS AND METHODS

2.1 THE STUDY AREA: PECKHAM TOWN CENTRE

In line with Transport for London’s ‘Improving the Health of Londoners’ Transport Action Plan, a safe and attractive urban environment can encourage people to walk and consequently to become more active. Similarly, there has been a long history of studies (Gehl, 1987; Hart, 2015; Hillier, 2007) that reiterate how accessibility is crucial for the development and sustainability of local economies and to reinforce a sense of place and the welfare of local communities. Peckham Town Centre was selected by TfL as a pilot location based on the number of pedestrians Killed or Seriously Injured (KSI) in recent years and the pedestrian safety risk.

The study area consists of almost 2km of the TfL’s Road Network (TLRN) and 3km of local authority roads. These links exhibit a wide variety of functions: the TLRN A202 providing a major east-west arterial route from Westminster to Greenwich; Rye Lane acting as the spine of Peckham and the centre for community activity and retail; and several side streets which serve as local routes to residential areas beyond. Further, the study area comprises a typically busy urban environment with mixed use, services and residential buildings, which sees both high levels of pedestrian movement and demand for a sense of place where local people can make use of local retail, social and community facilities.

The Peckham streetscape has remained largely unchanged over recent years and, apart from routine maintenance and street works, there has been no significant change to the road layout.

3 Defined as the rate of pedestrian KSIs per billion kilometres walked.
Conversely, in Peckham town centre, there are several examples of community severance, i.e. the local infrastructure acts as a physical and/or psychological barrier to the movement of people. For instance, the entrance to Peckham Rye Station is confusing, its visibility across Rye Lane is poor due to multiple obstructions, such as trader’s stalls, wastes and street furniture, on narrow footways, which also limit accessibility for less mobile people. Often, people were observed walking on the road itself, increasing the risk of collisions. The access between Peckham Library, a hub of cultural activities, and Rye Lane, the shopping destination, is another example of community severance. Despite being a signalised crossing, the crossing at the junction of Rye Lane and Peckham High Street is far from safe, as highlighted by the number of casualties over the past five years.

Figure 2 - Peckham Rye Station (left) and junction of Rye Lane and Peckham High Street (right).

2.2 COLLISION DATA

Within the five-year period studied (April 2010 to May 2015), the annual collision frequency in the study area was relatively unchanged, although KSI collisions of all types have reduced considerably. A total of 512 collisions were recorded in the study area, resulting in 576 casualties; of these, 118 (23%) collisions involved a pedestrian resulting in 121 casualties, which form the main database used in this study. It is also notable that Vulnerable Road Users (VRU’s), i.e., motorcyclists, pedal cyclists and pedestrians, account for 62% of all casualties in the town centre. Further, the data also showed that:

- Pedestrians, as a user group, account for the highest proportion of KSI’s in the town centre, demonstrating their vulnerability when involved in a collision.
- The proportion of pedestrians involved in collisions is increasing: from 20 in 2010-11 (19% of all collisions) to 25 in 2014/15 (26%) and averaging 24 over a five-year period.

5 An excel format summary of all collision and casualty records (selected STATS19 fields only) of collisions / casualties (between April 2010 to May 2015) for the study area and KeyAccident input files detailing all collisions, casualties and vehicle records for the study area (between April 2010 to May 2015).
6 Killed: A human casualty who dies within 30 days after collision due to injuries received in the crash. Serious injury: Injury resulting in a person being detained in hospital as an in-patient, in addition to all injuries causing fractures, concussion, internal injuries, crushing, burns, severe cuts, severe general shock which require medical treatment even if this does not result in a stay in hospital as an in-patient (IRAP International Transport Statistics Database - Safety Definitions).
Pedestrian KSI’s are reducing – from 2010-11 to 2014-15 there were 18 collisions with pedestrian KSI as a result (1 fatal and 17 serious casualties). Despite the increase in pedestrian injury collisions overall, the number of pedestrian injury collisions whereby a KSI injury occurred has reduced from 7 (2010-11) to 3 (2014-15) and averages 4 in number (similar to the downward KSI trend in the study area overall).

While the focus of the study was pedestrian KSI’s, due to their relatively low number and reducing trend overall within the study area, all pedestrian injury collision types were therefore considered in order to establish a greater evidence base.

Even if this first study does not distinguish factors like day of the week, time of the day, gender, age, type of vehicle, it is worth noticing that the contributory factors were quite informative. Overall, pedestrian behaviour (and not the driver) was seen as the significant issue in pedestrian-vehicle collisions, suggesting that poor pedestrian behaviour, such as failed to look properly or failed to judge vehicle’s path or walking speed as the main cause of collisions8. Most significantly, 80% of all pedestrian collisions and 60% of KSI pedestrian collisions occur at junctions, of these most are occurring at give-way / uncontrolled junctions. Further, approximately half of pedestrian collisions are classified as occurring at pedestrian crossings. All of these confirm the need of studying the on-street pedestrian perception and the spatial/design performance at the micro-scale.

A pedestrian collision ‘hotspot’ analysis (collision concentration9) have shown that out of the 18 pedestrian KSI collisions10, the majority are concentrated on (or just off) the A202 Peckham Road/ Peckham High Street /Queen’s Road corridor running east/west through the town centre comprising a total of 14 collisions (78%). Otherwise, all suggest that there are no distinct pedestrian KSI collision clusters elsewhere. Figure 3 illustrates the location of collisions according to the severity: fatal, serious or slight.

Figure 3 - Location of collisions within the study area according to the severity of collisions. Study area represented by the grey dotted line.

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8 Please note that the terminology such as ‘poor pedestrian behaviour’ or ‘failed to look properly’ is set by the policy while recording the collision.
9 The concentration of KSI collisions was defined when the physical proximity was less than 50 meters.
10 Fatal or serious cases only.
2.3 TRAFFIC AND PEDESTRIAN FLOWS DATA
The levels of both vehicle and pedestrian flows at each location were also considered for the analysis.

Pedestrian flow data was collected manually by the authors and Atkins Ltd employees during lunchtime on a weekday in 2015 covering most of the street segments along Peckham Road, High Street, Queen’s Road and Rye Lane providing enough information to consider pedestrian movement variability within the study area. Compatible traffic flow data was provided by the London Borough of Southwark.

2.4 DESIGN VARIABLES: PERS SURVEY
The Pedestrian Environment Review System (PERS) developed by The Transport Research Laboratory (TRL) provides a framework for assessing pedestrian provision in an urban environment. PERS has been applied to footways11 and crossings, which were assessed on-site using an audit checklist to quantify the quality of the streetscape. The process aims to review the environment from the perspective of different users, including the elderly, disabled, children and those with impaired mobility, in order to consider the inclusivity of the public realm12. Following the on-site survey, using the PERS v2 software, on-site scores were collected and weighted based on TRL weighting criteria, converting the assessment into quantifiable performance values13.

Peckham High Street and Rye Lane formed the focus of the PERS survey. Formal crossings have been examined on these roads and adjacent roads. In total 45 junctions were assessed with more than 100 crossings included as part of the review. Also, 16 segments of footways were also assessed. Overall scores have been noted alongside images documenting the full extent of the study area. Figures 4 shows the outputs of the PERS crossings and footways audit.

The results of the PERS assessment showed a number of issues, such as some uncontrolled crossings on the side road of major intersections, e.g. Clayton Road and Lyndhurst Way. On Rye Lane, there are fewer controlled crossings and pedestrians generally walk informally across the road. The study also noted that materials used along the length of Peckham High Street and Rye Lane have a low quality. Finally, it is worth to note that, for one same given location, crossings and footways do not always have the same consistent quality. Within the study area, one can find good quality crossings next to bad quality footways, and vice-versa, as well as locations with both crossings and footways with a good or bad perceived quality. In short, all combinations exist, which makes this study area perfect for this research.

11 Footways (also referred as links) were divided according to segments of consistent character and, in particular: (A) a significant change in footway width and (B) a change in adjacent land use. These two factors have been selected as they were considered to be the most influential aspects of the street environment, which impact on how pedestrians move through and across the street.
12 The assessment process for crossings looked at the following parameters: crossing provision, deviation from desire line, performance, capacity, delay, legibility, legibility for sensory impaired people, gradient, obstructions, surface quality and maintenance. The assessment process for footways looked at the following parameters: effective width, dropped kerbs, gradient, obstructions, permeability, legibility, lighting, tactile information, colour contrast, personal security, surface quality, user conflict, quality of environment and maintenance.
13 For both segments and crossings, the percentage scores attainable range from -100% to 100%, as follows: A) high quality (represented by green dots or lines): no immediate changes requires / only minor maintenance issues ranging from 34% to 100%; B) moderate quality (represented by orange dots or lines): generally operating satisfactory but could be improved ranging from -33% to 33% and C) low quality (represented by red dots or lines): critical issues identified requiring immediate attention ranging from -100% to -34%.
2.5 URBAN FORM VARIABLES: VISIBILITY GRAPH ANALYSIS (VGA)

Visibility Graph Analysis is based on how much space pedestrians can see as they move around. In dense urban areas, where there are many possible origins and destinations and a complexity of routes for pedestrians, pedestrians tend to choose the simplest path. This means that movement flows tend to concentrate on those streets that offer the simplest visual links through the street grid. Visibility (the area of usable space visible to a pedestrian at any point in the street grid) is, therefore, one of the most important factors determining movement. Pedestrian movement flows tend to be greater on routes that provide clear and direct visual links through the built environment than on complex routes where people cannot find a clear itinerary.
It is possible to quantify this ease of natural wayfinding within a computer model, using a methodology known as 'Visibility Graph Analysis (VGA)'. The software calculates the visual field available to pedestrians at every step of any possible journey within the network. This creates an overall measure of visibility of pedestrian space for any urban area, which can be mapped using a spectral colour range, where red indicates the highest levels of visibility through to blue, representing the lowest levels of visibility. Because of the often correspondence between visibility and pedestrian flows, VGA can be used as a representation for pedestrian flow levels.

In this study, VGA was carried out using the Fathom software developed by Atkins Ltd. Fathom calculates the visual field for a pedestrian standing at any point in the public space network. Taking accurate scale maps of an area as an input, a computer algorithm creates a 3x3 metre grid of sample observation points throughout the pedestrian movement space. The software then calculates the visual field and the number of points of interest at 360 degrees from each point in the grid by checking all directly visible points. The VGA outputs produced with Fathom are the following variables:

a) street network visibility (visible area at 50 and 500 metre distance);

b) spatial accessibility (visible area at 50 and 500 meters, directly or within one change of direction);

c) building entrances in view or natural surveillance\textsuperscript{14};

d) retail and food/drinks units in view;

e) access to bus stops; and

f) access to railway/overground stations.

The two first variables are expressed in square metres. The two next variables in the number of units in view and are calculated twice: only directly in view or also within one change of direction. Finally, the last two variables start from 1 (direct visual connection) and sum up 1 unit per each necessary change of direction.

As discussed, the desire lines, i.e., the routes of choice by pedestrians, can be identified based on the location of the red/orange (most visible) areas in the VGA processed maps. To that end, Fathom results highlighted important desire lines of pedestrian movement such as the diagonal route linking Rye Lane and Peckham Library across Peckham High Street (Figure 5a). Further, within the context of the study area, there is a clear retail centrality formed by Rye Lane and the central stretch of Peckham High Street, in strong contrast with most back streets within the study area, which lack active frontages (Figure 5b). Finally, despite their role as key pedestrian drivers, neither of the two train stations are located at the most visible/accessible locations, an element that we have further explored in relation to the location of collisions (Figure 5c).

\textsuperscript{14} The location and visibility of building entrances not only is an important factor in the concentration of pedestrian activity, but also an important aspect of the on-street safety perception. Building entrances provide a degree of natural surveillance of public spaces from building users themselves. Although windows also provide natural surveillance, building entrances offer the potential for a neighbour to intervene if a criminal act is being undertaken. The natural surveillance of an area is measured by the number of building entrances in view from every point within pedestrian areas.
Figure 5 - Three examples of VGA outputs. From top to bottom: A) visual accessibility (500m distance), B) access to retail and food/drink units (direct) and C) access to stations. The results are presented using a spectral colour scale from red (areas with the highest accessibility levels or number of retail establishments in view) to blue (areas with the lowest accessibility levels or number of retail establishments).
2.6 LINKING AND COMPARING COLLISIONS WITH SPACE AND DESIGN DATA

Using Geographical Information Systems (MapInfo Pro 15.2 software), the collision data was plotted against all spatial information. A 25-metre buffer area around each collision location was drawn and intersected with all other data to capture their properties. In case of intersection with more than one element, the aggregation method was the average weighted by length or area.

An important weakness of the study is that PERS results were not available for all collision locations. Also, some of the collisions did not happen near any crossing, so no crossing quality value could be associated. In contrast, urban form results were available for the whole study area.

Scatter plots have been used to display each pair of variables for the total of collisions. This sort of diagrams enables a combined comprehension of the two factors and their interrelationship. In this case, we compare urban form and land use variables with design quality values. This allows a quick visual understanding of the role of each variable.

We have produced a scatter plot for each pair of variables (Figures 7 and 8): one from the PERS design audit (x-axis) and one from the urban form analysis (y-axis). The minimum and maximum values in the study area are located at the ends of the axes, whereas both axes intersect at the study area average values (as in Figure 1). This chart allows an easy check of the distribution of collision locations according to those two variables and the four types of spaces in the study area.

Finally, after describing the location of individual collisions, these were aggregated per street segments so that relative ratios to compare with pedestrian and traffic flows were possible. Two ratios were calculated: number of collisions per segment length (km) and per vehicle flow (daily number of vehicles) and number of collision per segment length and per pedestrian flow (pedestrians per hour, total for both pavements and both directions).

These two ratios were compared with all urban form and design variables using Pearson’s correlations, in order to measure the degree of association between the collision ratios and the urban environment variables.

3. RESULTS

Firstly, the comparison of urban form and land use (pedestrian demand) versus design quality has been shown in the scatter plots. As introduced before, this enables a quick understanding of the distribution of collisions. Following the discussion on the four typologies of urban form caused pedestrian demand versus design quality, the number of collisions for each type has been calculated (Figure 6). It is evident that most collision points fall within the first two typologies: successful pedestrian spaces and unsatisfied-desire lines where there is high pedestrian demand, with a clearly lower importance of the design quality.

This is also further highlighted when reviewing the scatter plots (which follow the Space-Type Diagram typologies quadrants) and the consistent collision distribution pattern that is observed: whereas one can hardly see collisions plotted below the x-axis, they are common on either side of the Y-axis (Figures 7 and 8).

15 Regarding the missing data, for the urban form – design quality comparison, 39% of collision locations had no value for crossings, whereas 28% of them had no footway value. Instead of omitting these collision events, those were kept so that the urban form information would be displayed. Regarding representation in the scatter plots, they have been plotted on top of the axis as if they had average values.

16 Note that the collision points without PERS data have been counted twice within Q1-Q2 or Q3-Q4, depending on their urban form value, which explains why the sum of all percentages in Figure 9 exceeds 100%.
This means that all the urban form/land use variables showed a strong association with collision locations, with most collisions occurring in locations with a higher pedestrian demand potential than the average in the area. On the other hand, the design quality variables were not clearly associated with the distribution of collisions. Collisions took place in all kind of locations regarding the design quality spectrum.

In short, pedestrian collisions do not take place on 'unsatisfied-desire lines' only, but also in the better designed 'successful pedestrian spaces'.

<table>
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<tr>
<th>Crossings</th>
<th>Q1: Successful Pedestrian Spaces</th>
<th>Q2: Unsatisfied -desire lines</th>
<th>Q3: Back forgotten spaces</th>
<th>Q4: Red-carpeted deserts</th>
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<td>2.5%</td>
<td>11.9%</td>
</tr>
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</table>

Figure 6 - Percentage of collisions according to VGA measures and space type17.

17 Abbreviations stand for: VIS = street network visibility, ACC = spatial accessibility, BEIV = building entrances in view, RIV = access to retail and food / drinks units, BUSSTOP = access to bus stops, STATION = access to railway and/or over ground stations. 1=direct visibility, 2=direct visibility or within 1 turn, AVG = average value at location.
Figure 7 - Scatter plots: PERS Crossing (X) versus Urban form and land use variables (Y).
Figure 8 - Scatter plots: PERS Footways (X) versus Urban form and land use variables (Y).
To allow comparison between variables, another way to look at the results is the variation of the average value. What is the collision location average in comparison with the whole study area average? We have analysed the deviation for each variable range in the study area (Figure 10), using the formula below:

\[
\text{Average value variation (as %)} = \frac{\text{Average}_{\text{COLLISIONS}} - \text{Average}_{\text{STUDY AREA}}}{\text{Max}_{\text{STUDY AREA}} - \text{Min}_{\text{STUDY AREA}}} \times 100
\]

Regarding the morphological variables\(^\text{18}\), the results show that the more strategic configurational variables are (accessibility over visibility; 500m over 50m distance), the higher the variation (+18.63% for accessibility at 500m). The location of building entrances, retail units, bus stops and transport stations are all even more significant than the morphological variables, in that order of importance (+27.19%, +24.5%, +21.54% and +19.79% respectively). This is consistent with the literature in relation to pedestrian volumes, as described in the introduction.

The average value variation for the design variables is weaker. The quality of footways around collision locations is generally lower (-7.05%) than in the overall study area. Surprisingly, the quality of footways is slightly better (+2.11%) around the collision locations. This might be due to recent refurbishments at some of the busiest street segments, such as the northern end of Rye Lane.

\(^{18}\) They morphological variables are: street network visibility (visible area at 50 and 500 metre distance), spatial accessibility (visible area at 50 and 500 meters, directly or within one change of direction), building entrances in view or natural surveillance, retail and food/drinks units in view, access to bus stops and access to railway/over ground stations. Refer to Section 2.4.
Finally, regarding the two collision-flow ratios and the correlation with the urban form and design variables (Figure 10), the results showed to be not as consistent. Firstly, 14 out of the 24 correlations were not considered significant even at the 0.05 level (two-tailed). This could be expected given the low sample size (29 street segments) 19. Further, quite relevant to note is that none of the correlations with design variables were significant (consistent with previous results), as well as ‘combined variables’ such as pedestrian flows / vehicular flows ratio and pedestrian flows x vehicular flows. Looking at the significant results, we have (Figure 10):

a) For the similar levels of vehicular flows 20, the collisions per vehicle ratio shows that collisions are more likely to take place at locations with a higher number of building entrances (R=+0.39), retail units (R=+0.43) or close to a public transport station (R=-0.38). This would be consistent with our previous hypothesis and results: all these variables are a proxy for higher pedestrian flows and subsequently the higher the likelihood of a collision.

b) However, assessing separately the correlation between number of collisions and similar levels of pedestrian movement, it seems that collisions are less likely to take place at locations with higher number of building entrances (R=-0.39), retail units (R=-0.45) or close to a station (R=0.47). This might seem a contradiction with the previous results except that, in this case, the variability of these factors is not working as a proxy of pedestrian flows, given that the ratio is a relative measure per pedestrian. This would point at the interrelationship of these variables and traffic flow: in locations with a concentration of retail units, freight traffic and / or operations often have traffic-calming and speed reduction measures and bespoke schemes to safeguard pedestrians with a positive impact on pedestrian safety. This is the case of the north section of Rye, where only buses are allowed, so overall traffic flow is very low and the collision probability is lower despite the high retail concentration.

It is suggested that this might be related to the traffic-calming and speed reduction measures implemented in these areas, which reduce considerably the likelihood of collisions and the severity of injuries.

19 Further research with a larger data set (possibly including several areas in London and / or other urban areas) is needed to achieve more significant conclusions.
20 As a stand-alone variable, i.e., and disregarding vehicular flows.
Proceedings of the 11th Space Syntax Symposium
UNSATISFIED-DESIRE LINES:
A spatial approach to pedestrian collision analysis

4. CONCLUSIONS

Our analysis shows that there is a strong correspondence between the location of collisions and urban form and its configurational measures, including the number of building entrances, retail and food/drinks units in view and the location or transport nodes (bus stops and rail). This finding is consistent with previous research highlighting the key drivers for pedestrian movement that correlates with pedestrian flows and exposure to traffic. In sum, collisions are more likely to happen where people go.

Figure 10 - Correlation results, R values and possible interpretations.
However, the fact that design quality variables seemed to play no significant role in the location of collisions is surprising, especially if we consider that most pedestrian safety guidelines are very design-focused.

It could be argued that the PERS method might not reflect the design characteristics affecting safety well enough. In fact, previous literature has focused on the type of crossings, traffic lights and other elements, rather than the on-street perceived quality of design.

However, this study shows that ‘unsatisfied desire lines’ are not the only types of spaces in which collisions take place. Locations with the highest design quality also host collision events and are not necessarily safer. Consequently, pedestrian safety strategies based on design only may not have the expected level of impact and success.

Our research suggests that an analysis of urban form and land use is key to identify the pedestrian ‘desire lines’ and exposure to collisions. The holistic understanding of the spatial hierarchies of pedestrian movement in a given environment can guide other initiatives, such as the strategic location of design investment, traffic-calming areas or behavioural change programmes. It would also identify the areas where the highest traffic flow itineraries are a threat and should be deviated.

Further research with a larger data set (possibly including several areas in London and / or other urban areas) is needed to strength the initial findings of this research.
REFERENCES


Hillier, B. and Hanson, J. (1989), The social logic of space. Cambridge: Cambridge University Press.


ABSTRACT

This contribution is part of a PhD research. The study investigates the factors related to the vitality of street life in Brazilian cities. To what extent play urban form a part in forging the vitality of street life and why? What is the impact of the urban planning regime on the relation between urban form and vitality? That second factor will be further explored in this paper. Our research question is: to what extent have space syntax contributions been extensively identified and classified so that planning codes of a city can make practical use of them? In other words, is it possible to have a shared language between space syntax and urban planning codes? The initial case study in this research is the city of Recife in the northeast of Brazil, a city that has been extensively discussed in previous space syntax symposia.

The first part of the article reveals the spatial parameters commonly regulated in the planning instruments of Recife. In a second part, space syntax theory and methods developed for micro-scale analysis are used to describe the transformations in the urban environment. That part investigates the impact of the utilisation of the current municipal rules and the possible effects related to urban vitality. Once again, this study will focus on the building frontage and nearby spaces. Finally, a discussion to what extent the space syntax research results and convergences can be decoded into the language used in planning instruments is appropriate. As it turns out, there is a need to develop an operational conceptual framework accessible for planners. In short, this study presents contributions to the formulation of urban norms.

KEYWORDS

Urban codes, spatial configuration, planning instruments.

1. INTRODUCTION

Space syntax is mostly regarded as a sociospatial theory, capable of decoding the materialities of social – spatial relations using "models, which are regularities in the relation between spatial structures and functioning" (Hillier 2009). Our research question is: are these regularities extensively identified and classified so that planning codes of a city can make practical use of them? In other words, is it possible to have a shared language between space syntax and urban planning codes? That question deals with two aspects, on the one hand, it resonates the challenges presented in previous studies regarding the combination of space syntax methods with urban morphology (Netto et al. 2012; Pont & Marcus 2015; Gkanidou et al. 2015). On the
other hand, it searches for applications of what Hillier identified as the primary aim of space syntax, "to arrive at spatial descriptions of buildings and cities with the minimum intervention of linguistic concepts" (Hillier 2013). In that sense, this research aims at the micro-scale level, an emerging field of study using space syntax theory and methods that have shown a significant relationship between spatial configuration and street life (van Nes & López 2007).

This contribution is part of a PhD research. The study investigates the factors related to the vitality of street life in Brazilian cities. To what extent play urban form a part in forging vitality of street life and why? What is the impact of the urban planning regime on the relation between urban form and vitality? The definition of vital street life and urban vitality in this inquiry is that people stay and use public spaces and that adjacent buildings have activities on the ground floors oriented towards the streets. The aim of the research is to investigate how urban rules or the set of norms and planning devices of a given city can be structured to foster urban vitality in the public domain. The initial case study in this research is the city of Recife in the northeast of Brazil, a city that has been extensively discussed in previous space syntax symposia.

One of the hypotheses of this research is that urban rules are determinant to define a space where street life and urban vitality can thrive. That is extremely relevant in the Brazilian setting and particularly in the case of Recife where the action of the real estate market associated with a reduced role of planning institutions has resulted in a severe physical disruption regarding opportunities for street life.

This reflection resounds the thesis proposed by Lucas Figueiredo (Figueiredo 2012) in his article ‘Desurbanismo: Um manual rápido de destruição de cidades’.

‘The growth and development of several Brazilian cities during the past two decades was not just random or disorganised. It produced, predominantly, architectural typologies, spaces and transportation systems that favour a few ways of life over all others. This disurbanism has feedback loops that create physical structures that hinder other ways of life while resulting in cumulative advantages for the favoured ways, a spiral that continually produces new disurban trends’ (Figueiredo 2012).

In his writing, Figueiredo explores five processes that are, according to him, responsible for the urban destruction in Brazilian cities: growing use of cars, lack of quality in public transportation, high walls and gated communities, loss of diversity and adaptability of buildings and segregation of people and ideas. In this article, we trace the origin of these architectural typologies, relating their elements and spatial configuration with a set of planning instruments.

The first part of the article reveals the spatial parameters commonly regulated in the planning instruments of Recife. That is demonstrated through a retrospective of the planning codes of the last decades (Carvalho Filho 2014), analysing and relating planning regulations to specific spatial parameters and the resultant spatial configuration. In this article, the focus will be on the interface between public and private domains, analysing the role of planning instruments in the shape of this border.

In a second part, space syntax theory and methods developed for micro-scale analysis are used to describe the transformations in the urban environment. That part investigates the impact of the utilisation of the current municipal rules and the possible effects related to urban vitality. Once again, this study will focus on the building frontage and nearby spaces. Finally, a discussion to what extent the space syntax research results and convergences can be decoded into the language used in planning instruments is appropriate. As it turns out, there is a need to develop an operational conceptual framework accessible for planners. In short, this study presents contributions to the formulation of urban normative.

1 Some of the previous papers presented at various space syntax symposia about Recife discussed in more detail certain aspects that are discussed in this article such as: the fragmented spatial configuration of the city (Carvalho Filho et al. 2015), the role of private spaces and real estate market (Amorim & Loureiro 2003) and safety perception and crime (Monteiro & Cavalcanti 2015).
1.1. DILEMMA

Before starting the analysis of the planning instruments and the contribution of space syntax theory, there is a dilemma or apparent contradiction that must be clarified. This paper deals with urban rules understood as a translation of larger plans or visions into a set of parameters that once applied will result in a given spatial configuration. The aim of this research is to evaluate the effectiveness of these instruments in fostering spatial quality, urban vitality.

These tools are commonly plot based and are responsible for guiding the incremental construction of the city by aggregation of individual buildings. Therefore the domain of action of urban rules is centred in the local properties of spatial configuration.

Natural movement theory puts that "If we wish to design for well-used space, then we must design with the knowledge that integration is a global variable, and movement in particular spaces is not determined in the main by the local properties of that space, but by its configurational relation to the larger urban systems" (Hillier et al. 1993).

That apparent contradiction in the scale of action, local – global, opens the questions about the effectiveness of rules applied on a local level and that affect the global configuration in an indirect and incremental way, to what extent can space syntax contribute to the formulation of these instruments. In that sense, this research continues the investigation about micro-scale spatial variables and builds upon the findings that "the micro-spatial conditions of the street segment are related to the macro spatial conditions of the city network" (van Nes & López ibid).

The local configuration can provide elements to reinforce and sometimes contradict (Netto et al. 2012) the results of the global analysis. However, combined analysis represents an approach to have tailored methods to deal with specific contexts (Pont & Marcus 2015).

To overcome the dilemma local – global one must also consider the usual dual scale of tools or rules. Although rules are locally applied, they must be placed in specific parts of the city according to a reading of the global configuration, in that case, the relevance of global configuration is reinforced. For this paper, we focus on the local scale and the spatial configuration of plots and blocks in relation to the whole city’s street network integration.

2. PLANNING INSTRUMENTS IN RECIFE

The review of the planning tools in Recife in the last decades that will follow intends to identify the mechanisms related to design control, whether it is explicit or not in the laws texts. It is an attempt to identify ‘the process of state-sanctioned intervention in the means and processes of designing the built environment in order to shape both processes and outcomes in a defined public interest’ (Carmona 2016).

Recife has to some degree experienced pioneer interventions in planning such as the partially implemented plan for the expansion of the city. It was commissioned in 1637 by Nassau during the Dutch domination of the region (1630-1654) and are regarded as one of the first urban propositions based on physical interventions in the Americas (Medina 1997).

In general, planning in Recife can be organised into three main periods that somehow correspond to three main planning doctrines as pointed by Sarah Feldman when studying the evolution of planning practices in Brazil (Feldman 2001).

In the period preceding the first two decades of the 20th century, there was a dominant European tradition in the formulation of laws and postures that governed construction in the city. These regulations were mainly focused on hygienist and aesthetics aspects.

The decades of 1920 – 1930 are a period of transition where there was a shift from the European tradition to the adoption of certain postures that referred more to American planning practices, such as zoning plans and parkways for example.

The last period proposed by Feldman, post 30’s is the one under the influence of Modernism. The first shift was towards a higher level of flexibility in the planning instruments, greater
involvement of architects and planners in the decision process and a following change in the urban fabric by the transformation of the parcels and land use.

2.1. THE PERIOD BEFORE 1920

As stated before, the regulations of that period are mainly addressing hygienist and aesthetics aspects of the construction of the city. That is evident in the importance given to the control of street alignments, in the location of different activities in the city and the regulation of built environment regarding open space.

From that period are the Municipal Law 4 from 1893 and the Law 1051 from 1919. The first one is a Municipal Code of Postures, instrument established in the country by federal law where planning tools were still part of the main body of the city regulations. The language and scope of the legislation from that period do not address specifically those involved in the design and construction of the city. It was a broader instrument to assess how the city should perform in general addressing many aspects, not only those related to land use or typomorphology.

The second one, law 1051, shows already some degree of specialisation regarding the first, there was an overall conception of the city based on an underlying zoning plan that determined four perimeters in the city, main, urban, suburban and rural. In this first division of the city into zones, there was, as observed by Alves (Alves 2009) a prejudiced organisation of the city by income and social level by defining what type of construction was permitted in each zone. For example, not allowing in the main centre of the city the building of the kind of dwellings inhabited by low-income population.

Regarding urban form, there was a clear connection and hierarchy between the building and public space related to the zoning. The spatial result of this instrument was a radioconcentric configuration where the density of occupation was higher in the centre and incrementally lower towards the limits of the urban area following the indications of the previous law.

The maximum height of the buildings was different in the zones and proportional to the width of the streets, ranging from 2 times the street width in the central zone, 1 ½ and 1 in the urban and suburban zones respectively. The minimum setback from the buildings also varied, from 0 in the centre to 3 to 5 in the successive zones. In the central zone, all constructions should be built observing the general alignment of the streets; there was also a minimum height limit and some artifices to allow taller buildings such as the construction of arcades along the streets.

2.2. 1930 – 1960’S

In Recife, that period is initially characterised by a revision of the law of 1919 in 1936 that introduces new subzones into the existing zoning plan. Functional subzones are created inside each of the first zones, defining different parameters for buildings according to their function. Another point introduced by this review was the introduction of the figure of coverage or percentage of the plot that could be occupied.

In the last years of this transition period, two new laws or decrees adjusted some of the parameters imposed by the law of 1936, the Decree 27 of 1946 and the Law 2590 of 1953. The first one changed the height limit in the city centre, aligned to the image of the modern city. The 1953 law changed the borders of the urban area, expanding it to the south following the expansion of the city observed along the beach front. It also increased the building coverage in that zone, maximising the construction potential.

In 1961 the law 7247 reviews the construction regulation of the city that dated from 1936. This revision represents an expansion of the urban area towards the west and the creation of distinct zones regarding the port, commerce, industry, universities and nature reserves. Segregation of low-income residents of the urban area is still part of the law as it states specific conditions for the location of new developments targeted to that part of society. Those housing complexes could not be located close to public spaces or main streets.
2.3. 1980-1990’s

The law 14511 from 1983 represents a significant shift in planning regulations in Recife. Such change is represented by the disconnection introduced in this act between public and private spaces in the formulation of the parameters to regulate construction. As pointed by Medina (Medina 1997) the introduction of accurate and detailed parameters to control the use of plots, in a system of zones, represents the total inversion in the symbolic value of public – private domains, transferring to the individual plot and housing units the central role in the city regulations.

That shift in importance to the housing sector and plot scale is perceived in the zoning as higher allowed densities are now found in the city expansion in the south, no longer at the city centre. The detailed and specific parameters introduced in this law are not only related, like in previous instruments, to different zones but now they are dependent on the building function. That relation between parameters and function promoted an occupation of the city in a generic way; buildings are planned detached from the specific local conditions. Such aspect resulted in a reaction from inhabitants from certain historic districts that led to the establishment of more restrictive parameters, reducing maximum building height, in some of these zones.

In 1996 the law 16176 replaces the previous instruments and promotes a drastic revision in the zoning patterns and the construction parameters. It almost eliminated the relation between parameters and land use, and there is a simplification of the city structure.

The major differences between construction parameters in the zoning are related to coverage, initial setbacks and green ratio. In the areas where construction was expected to be less intense, the green rate reached 50% of the plot, and maximum coverage was of three times the plot area. Repeating a pattern described previously, the regulations in this law had unexpected results that generated a public reaction and had to be fixed in a set of new rules.

The law 16719 from 2001 addressed the excessive construction observed in some districts of Recife, mainly following the river. Maximum height for buildings was introduced in this area per a classification of streets. Height was restricted from eight to twenty floors and typically followed the location of the roads regarding the river or historic areas.

2.4. CURRENT PLANNING INSTRUMENTS

In 1988 the Brazilian Constitution established the Plano Diretor as the core tool for development and city planning. Every city with more than 20 thousand inhabitants is obliged since then to

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2 Master plan or zoning plan are not accurate translations for the term as Plano Diretor involves zoning, building regulations but also a set of broader goals for the city’s future, regarding public health, education, housing etc.
have a Plano Diretor and to review it every ten years. After the federal law now as Estatuto das Cidades (2000) this obligation has been extended to cities that are part of metropolitan regions, conurbations and inserted in special zones such as environmental or historical. In the same federal law, it was also stated that Plano Diretor should be participative.

Recife latest planning rules are represented in the Plano Diretor of 2008. This instrument introduces a more detailed zoning system than the existing in the previous tools but remains attached to the urban plot as the core unit for planning. The figures regarding the potential for construction and maximum densities are reduced in the city. However, there is a change in the way the area of development is calculated that reduces the impact of reduced building parameters.

In previous regulations when it was stated the building intensity (floor area ratio) it meant that the maximum construction in a plot included private and common areas. In the current instrument, parameters apply only to private areas. That fact combined with the larger number of mandatory parking units demanded by the law contributes to the creation of massive street plinths containing ground floors of buildings just to house cars.

Another change regarding this instrument is the regulation of the frontage of buildings; it is stated now that 70% of the front of a plot must be transparent, not allowing anymore the long blind walls that characterise large parts of the city. It is also defined that the requested green area of a plot should also be in the front setback. That represents a change in the visual aspect of the border between private and public spaces. However, this law hardly advances in providing the means to have a more active frontage.

2.5. HOW PLANNING INSTRUMENTS SET THE SPATIAL FRAMEWORK FOR URBAN TRANSFORMATION

The planning rules discussed here cover a relatively short time span regarding the history of the city. However, these rules have been responsible for controlling most of the formal urbanised area of the city. These instruments vary in complexity and scope. Still, some conclusions are possible, always trying to relate these plans or laws to their effect on the spatial configuration and restricting the findings to the most important aspects observed.

There can be identified a cycle of policies and legislation that go from a more generalist to more detailed approach. That can be the result of the fact that more detailed and elaborated laws like the one of 1961 that had a very fixed setting of typologies and parameters somehow constrained the action of real estate market. That constraint was reduced in the successive plans by a more general zoning of the city and in a higher dependency on spatial parameters to regulate the construction in the city.

What can be understood primarily from the analysis of law 16176 of 1996 and the instruments that followed it is that these tools are generalising the different spatial features of the city and relying exclusively on parameters that are usually insufficient to deal with the city complexity. Even the more complex zoning plans like the new Plano Diretor of 2008 still lacks some instruments to allow a better negotiation between public and private sector.

In that sense, prior tools like the 1919 law were more efficient as they provided clear elements to the negotiation to mitigate the impact of constructions of the limits stated in the law. Spatial solutions to deal with higher construction levels were embedded in the law; one example was the creation of public arcades to allow taller buildings. It is evident that the contemporary city and its scale of constructions involve much more questions than in the past, but modern instruments hand to private negotiations, and normally monetary compensations, the mitigation of projects with higher use than the parameters established in the law.

That is a clear result of what happened in a given moment where can be observed a dissociation between the instruments that regulate zoning and land use from those that deal with typomorphology. In short, more recent laws have set rules to be applied to the plot, restricting
building capacities in a more detached relation with the territory. Moreover, it is the result of the move from plans that envisioned a spatial configuration for the city, or at least to certain zones, to those that deal with the city based on the control of constructions in almost exclusively in a plot scale.

What has been described so far is that, in general terms, planning in Recife is reactive. The reading of planning instruments presented here shows that, in most cases, the tools could not cope with the pace that market operates and that the time necessary to adjust urban regulations leaves space for problems to persist even after their impact has been realised.

Most of the tools reviewed here deal with the allocation of different densities and functions in the city territory. However, the zoning of land uses was and still is to some degree more focused in the restriction of certain land uses than concerned in providing diversity in the city matrix of land uses.

3. PLANNING INSTRUMENTS AND THE DESIGN OF AN INTERFACE

Urbanites experience their cities in what we call the ‘public realm’. It has a broader meaning than just ‘public space’; it includes façades of buildings and everything that can be seen at eye level (Karssenberg et al. 2016). In this section, planning instruments will be codified using this notion of the public realm as a framework. The elements that compose this realm will be identified and observed in the different instruments that were employed in Recife in time.

Urban rules are in general associated with a design strategy. It is an attempt to codify concepts and delivery parameters that are sufficiently structured to guide the construction of a desired spatial configuration. They represent creative acts that solve definite urban problems – and sometimes even create them (Lehnerer 2009).

In the instruments analysed in the previous section, it was possible to identify the most common parameters used, how they have changed, have been simplified or made more complex, as laws were updated. In the table bellow, a synthesis of the parameters is presented.
Table 1 - Main spatial parameters identified in the laws.

<table>
<thead>
<tr>
<th>Law</th>
<th>1051</th>
<th>7427</th>
<th>14511</th>
<th>16176</th>
<th>16719</th>
<th>17511</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum setback (front)</td>
<td>null</td>
<td>null</td>
<td>3 to 7 m</td>
<td>3 to 7 m</td>
<td>5 to 7 m</td>
<td>5 to 7 m</td>
</tr>
<tr>
<td>Maximum height (total)</td>
<td>Related to street width</td>
<td>Related to street width</td>
<td>Defined per zone</td>
<td>Defined per zone</td>
<td>12 to 25 floors</td>
<td>Defined per zone</td>
</tr>
<tr>
<td>Maximum height (plinth)</td>
<td>Not informed</td>
<td>Not informed</td>
<td>6.0 m</td>
<td>7.5 m</td>
<td>7.5 m</td>
<td>7.5 m</td>
</tr>
<tr>
<td>Floor area ratio (FAR)</td>
<td>Not informed</td>
<td>Not informed</td>
<td>Not informed</td>
<td>1 to 5</td>
<td>1 to 5</td>
<td>1 to 3</td>
</tr>
<tr>
<td>Building coverage ratio (BCR)</td>
<td>Not informed</td>
<td>30 to 50%</td>
<td>30 to 50%</td>
<td>Not informed</td>
<td>Not informed</td>
<td>Not informed</td>
</tr>
<tr>
<td>Green coverage</td>
<td>Not informed</td>
<td>Not informed</td>
<td>25 to 50%</td>
<td>25 to 50%</td>
<td>25 to 50%</td>
<td>25 to 50%</td>
</tr>
<tr>
<td>Parking demand</td>
<td>Not informed</td>
<td>Not informed</td>
<td>01 parking at every 80m²</td>
<td>01 parking at every 40m³</td>
<td>01 parking at every 40m³</td>
<td>01 parking at every 40m³</td>
</tr>
<tr>
<td>Frontage</td>
<td>Commercial use in certain areas</td>
<td>Commercial use in certain areas</td>
<td>Not Informed</td>
<td>Not Informed</td>
<td>Not Informed</td>
<td>70% must be transparent</td>
</tr>
</tbody>
</table>

The application of the parameters above has resulted in a series of different configurations regarding the building interface. As one can see in the table above, the change in the parameters is apparently subtle in most cases, but the spatial result can be extremely various. It is therefore expected that each of these profiles has a different impact on urban vitality. That reinforces the role of rules in the shaping of the urban setting and corroborates what Bernardo Secchi (Secchi 2015) says about the role of urbanism and planning devices. "What changes down the history of the city is much more the regulatory sense and role of each device rather than the catalogue of devices, and it is through this regulating action that the city becomes a machine for social integration or exclusion as the case may be" (Boano & Astolfo 2014).
Figure 2 shows three types of building-street interfaces used in this study. These typologies represent a considerable variation regarding spatial configuration on a micro-scale level. The first type is the urban gallery building. The urban gallery building has an active frontage towards the public street on ground floor level. The functions inside the building are well connected to the public street. The second type is the pilotis building, where the ground floor level consists of one open space typically used for parking or leisure. The building is standing on pilots, and, apart from a visual connection, there is no direct interface between the areas inside the building and the public street. Often these areas tend to be semi-private. The third type is the tower on the podium building, where the ground, the first and sometimes second floors are used as a parking garage. This kind of parking "podium" has no permeability and inter-visibility from the building towards the public street. It creates large blind walls and streets where no-one wants to stay, it has adverse results on street life, and it represents a long process of setting up a new private order (Caldeira 2000).

The following sequence of maps show both an angular choice analyses with a metrical high radius and a metrical low radius respectively and with the locations of the three typologies.
Figure 3 and 4 show angular choice analyses with a metrical high radius and a metrical low radius with the locations of urban gallery buildings. Buildings of this kind are located along highly integrated primary routes that are well connected to a city and neighbourhood scale. These buildings are not located in the highly locally integrated low-income settlements found on the hills, but in the neighbourhoods that have high local integration values. The urban gallery building contributes to street life due to both high integration on the street network as well as...
that a building type of this kind has an active frontage towards the street on ground floor level. The previous two figures show an angular choice analyses with a metrical high radius and a metrical low radius with the locations of pilots buildings. Buildings of this kind are located along segregated streets on all scale levels. Taking into consideration the weak natural surveillance mechanism between buildings and streets, the location of the pilot buildings scores very low on the degree of spatial integration and connectivity on macro as well as micro-scale levels.
The last type analysed, represented in Figures 7 and 8 has the lowest overall performance. In general, the towers on podium buildings are located along poorly integrated streets on local as well as city scale level. In addition, as mentioned before, this building type contributes to a disconnection between buildings and streets on a micro-scale level.
Figure 9 - Street segments connected directly to each building typology. Source: Author’s own.

<table>
<thead>
<tr>
<th></th>
<th>Recife</th>
<th>Urban Galery</th>
<th>Pilotis Building</th>
<th>Tower on Podium</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Local</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>11</td>
<td>880</td>
<td>559</td>
<td>196</td>
</tr>
<tr>
<td>Max</td>
<td>734.310</td>
<td>235.192</td>
<td>176.900</td>
<td>192.924</td>
</tr>
<tr>
<td>Mean</td>
<td>15.992</td>
<td>2.512</td>
<td>13.844</td>
<td>13.627</td>
</tr>
<tr>
<td><strong>Global</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min</td>
<td>9.753</td>
<td>63.431</td>
<td>42.965</td>
<td>40.198</td>
</tr>
<tr>
<td>Max</td>
<td>365.360.130</td>
<td>263.462.210</td>
<td>353.687.140</td>
<td>353.687.140</td>
</tr>
<tr>
<td>Mean</td>
<td>3.310.119</td>
<td>11.276.674</td>
<td>5.245.867</td>
<td>5.530.943</td>
</tr>
</tbody>
</table>

Table 2 - Summary of the values for angular choice

The next step is to reveal in detail how these three building typologies have an impact on street life through registrations of human behaviour and a fine-tuning of the microscale methods. For this paper, we focus on the spatial parameters for the building on the podium typology, as it represents the application of the current planning instruments and has been more recurrent in the city during the last decades.

3.1. SPACE SYNTAX AND THE LOCAL SPATIAL CONFIGURATION

Some characteristics of Recife emphasised in this research makes the analysis of the impact of the local configuration complicated for measuring the spatial factors for urban vitality. The most relevant issue, in this case, is that the city has been gradually transformed, mainly by the substitution of buildings. This process is not uniform, most of the time several types of construction can be simultaneously found in a single block. That shows how every set of regulations has affected building typology and that there is hardly any continuity line in the definition of spatial parameters embedded in the urban rules. That makes difficult the application, in the current case, of methods based on uniform contexts or planned areas to evaluate the effect of a local configuration to urban vitality.
In this regard, the micro-scale tools represent a set of analysis that allows us to have a first approximation on the contribution of space syntax in the formulation of urban rules. The procedure used here analyses a certain number of blocks in the city, evaluating their performance before and after the transformation of the building setting as a consequence of the application of the current urban rules. The features that have been compared are the topological depth between public and private spaces, the degree of inter-visibility of windows and doors, the level of constitutedness, the average floor area ratio and the average number of dwellings. This comparison of the performance of the features listed above uses data from the municipal cadastre complemented with average values from areas with a similar pattern of construction.
Figure 10 - Example of the analysis of the transformation on a street profile using micro-scale tools. Source: Author’s own.
### Table 3 - Initial results of the study comparing 15 street segments in 03 areas.

<table>
<thead>
<tr>
<th>Parameter (average)</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topological depth</td>
<td>1 step</td>
<td>2-3 steps</td>
</tr>
<tr>
<td>Inter-visibility</td>
<td>85%</td>
<td>20%</td>
</tr>
<tr>
<td>Level of constitutedeness</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>Floor area ratio</td>
<td>0.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Number of dwellings per plot</td>
<td>1.5</td>
<td>25</td>
</tr>
</tbody>
</table>

One might expect that higher density in construction and an increased number of households would be beneficial for street life. However, that is not necessarily the case in Recife. This process of upscaling properties, as demonstrated here, contributes to reducing the interaction at ground level, as several front doors are replaced by one gate, and generally, no public function is provided at the base of these new buildings.

What is at stake here is the loss regarding adaptability and potential for the vitality that resides in a more fine-grained urban fabric. It is not the fact that small plots built with houses have already a diversity of functions, but they are considerably more adaptable than a single building where the plinth is frequently occupied with parking space (Carvalho Filho 2014).

In the next phases of this study, the samples will be expanded to include other types of street interface, and the effects on the street life of the different configurations will be assessed by comparing data regarding the location of micro-business, pedestrian counting and observations on site.

### 4. CONCLUSIONS

Some of the adverse effects on the micro-scale spatial relationships demonstrated here can be considered inevitable in the context observed in Recife of substitution of detached houses by larger buildings. Planning instruments frequently, with very few exceptions in specific zones related to nature reserves or historical areas, do not pose any restriction to merging of smaller plots. On the contrary, combining and upscaling plots is indirectly stimulated by regulations that make difficult to build on smaller terrains. In the construction regulations, initial setbacks and demands for parking are rather constant regardless the dimensions of the plot what restricts the densification in small parcels. In that case what would be the contribution of space syntax theory? As pointed out by van Nes and López (2007) urban developments are typically guided by high-density figures, and the degree of interconnectivity and the topological shallow public-private interface is often forgotten.

Examples of previous rules used in Recife show that it is possible to conciliate larger buildings with lively streets by the use of spatial devices such as the commercial galleries on the ground floor. The contribution of the methods employed here can be, by expanding the studied sample areas, and by relating the syntactic and morphologic analysis with the location of the micro business, pedestrian flows, to come up with thresholds that represent ideal conditions for street life. In other words, further research on the topic can clarify how incremental changes in the local urban configuration can bring benefits to the larger scale.
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STRATEGIES FOR INTEGRATED DENSIFICATION WITH URBAN QUALITIES
Combining Space Syntax with building density, land usage, public transport and property rights in Bergen city.

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ABSTRACT
Bergen city in Norway is presently undergoing an enormous population growth. In this respect, Bergen municipality wanted to identify all the possibilities for densification in the current situation. Therefore, the following issues were evaluated: street network and public transport accessibility, building density, degree of functional diversity, restrictions on (private) properties and current land use plans.

Our approach is to analyse the central areas in Bergen in the current situation to discover how the urban transformation takes place in a natural way. Firstly, we studied the relationship between street network accessibility (with the Space Syntax method), degrees of FSI and GSI on building density (with the Spacematrix method) and degrees of function mix (with the MXI method). Secondly, we wanted to reveal the legal issues that arise from the strong Norwegian property rights. Thirdly, we added the accessibility of public transport lines through the angular step depth in the Space Syntax analysis. We combined all these issues by using GIS. Unlike in earlier research (Ye and van Nes, 2013 and 2014), the buffer line function in GIS was used to correlate building density, function mix and degree of spatial integration.

It turns out that the degree of street network integration affects the location of commercial activities and the degree of building density and function mix. When the street network accessibility increases on a local and global level, property owners start to submit plans that exploit their properties to the utmost. The same occurs around public transport stops with frequently running light rail trams. As follows from the theory of the natural urban transformation process, densification can thus be steered by improving the street network accessibility on multiple scale levels, combined with high public transport accessibility.
KEYWORDS
Building density, land use mix, property rights, public transport, natural urban transformation.

1. INTRODUCTION

During the last years, the use of GIS has contributed to combine the results from spatial analyses with place-bound socio-economic data. GIS has made it possible to operate with big data and to combine them with one another. The combination of building density (the correlation between FSI with GSI), degree of function mix (MXI) and Space Syntax in old and new towns has contributed to knowledge on how these aspects are interrelated (Ye and van Nes 2013 and 2014; van Nes et al., 2012). Already now, an outline is formulated for a theory of the natural urban transformation process. According to this theory, the spatial configuration of the street and road network influences the degree of building density and the degree of multi-functionality in the natural transformation processes in neighbourhoods over time (Ye and van Nes 2014). Lively and vital urban environments are thus dependent on a combination of a highly spatially integrated and well-connected street pattern, high building densities and a high degree of function mix.

Current planning policies in Europe are putting smart growth, high building density and high diversity of urban functions within short walking distances on the agenda to create compact cities. However, the social and environmental sustainability of building a compact urban form is disputed (Rådberg 1996:385). The compact city has the advantage of short walking distances between buildings containing its various activities. The ecological footprint is relatively small due to a reduction of urban sprawl. There are advantages to social and economic intensity because a high number of people live close to each other. From an environmental perspective, energy usage of transport between functions in compact cities is low. However, there is a lack of green spaces for recreation or for agricultural activities. Green and sustainable cities on the other hand have positive connotations in terms of well-being, attractiveness and sociability. The green city has the advantage of being able to provide its inhabitants with recreation and possibilities to produce food. In contrast, green cities contribute to urban sprawl into the countryside when the city expands. This contradiction between green cities and compact cities continues to prevail in urban design and practice (Rådberg 1996).

High building density is considered to contribute to sustainable development because it implies sharing of buildable space, facilities and infrastructure, as well as the reduction of travelling distances. This sharing implies a reduction of land use and energy resources required to perform all kinds of urban activities. The degree of success of this sharing can thus be seen as an indicator for an area's degree of urban quality.

If density is desirable as one of the requirements for urban quality, then urban development projects should always facilitate for maintaining, and where possible, further increasing density. Jane Jacobs (2000) and Jan Gehl (2011) argue that sufficient density is a requirement for life between buildings. More importantly, life between buildings is “potentially a self-reinforcing process”, in which, “once this process has begun, the total activity is nearly always greater and more complex than the sum of the originally involved component activities” (Gehl, 2011:73). In other words, a successful urban area is self-propelling by merit of the amount and duration of outdoor activities, which requires both sufficient density and high-quality public spaces to ensure that a high number of people enjoy using these spaces.

Therefore, if density is a prerequisite for sustainable use and the amount of outdoor activities an indicator for the degree of success of performing these activities, then a spatially integrated urban street network is the primary generator of sustainability in the context set out here (see also: Hillier et al., 1993).

The next step is now to reveal how public transport accessibility plays a role in the natural urban transformation process. In 2009, Bergen city in Norway opened a light rail connection. The line was extended in 2016 and the last part of it will be opened summer 2017. The effect of the light rail is that surrounding property prices are increasing. For that reason, public transport
accessibility was included in the calculations of street network accessibility by mapping the angular step depth from public transport stops.

One obstacle for large scale urban planning and transformation of urban areas in Norway is the strong legal issues related to private property rights. It is even stated in paragraph 105 of the Norwegian constitution law from 1814 that no one should be dispossessed of their private property, and if so, they should be given full compensation (Backer and Bull 2016, p. 12). Therefore, urban expansions in Norway tend to take place on large plots where one has to deal with a low number of property owners. Large-scale urban renewal projects or big inner city transformations thus involve time-consuming negotiations with property owners and adjustment of property borders, as well as high costs of changing property borders when a large number of owners are involved.

The background for the research is a project set up by Bergen municipality that intends to explore where and how to densify in existing urban areas. The aim is to use the outcomes in future land use and policy planning as a strategy for densification in the central areas of Bergen. Inspired by the ‘Denser Stockholm’ project (Spacescape 2013), a Spacescape analysis is made using a densification rose to identify both the need for densification and there where there is freedom to do so. How to densify in those areas depends on the degree of accessibility of the street network and public transport, as this inquiry shows. To that end, the Space Syntax method is included in the research project.

The project started with an identification of the types of densification actions proposed by the municipality. Three types of densification actions were identified: intensification, transformation and expansion. The intensification strategy entails identifying densification potentials in existing urban areas without changing the whole built environment. The transformation strategy concerns identifying and assessing densification potentials of larger urban areas that would require a functional transformation, such as harbour fronts, goods terminals and industrial estates. The expansion strategy intends to find densification opportunities in previously unbuilt areas within the city boarders. In the Bergen case, these are often found on the mountain slopes, where development had not previously been considered due to costly technical challenges.

Following the theory of the natural movement economic process (Hillier et.al, 1993 and 1998), it is to be expected that the highest potentials for densification outside the city centre are found around the main routes, the local centres and the public transport stops. Local discrepancies may be found which can likely be attributed to the unique landscape elements such as the mountain slopes and fjords surrounding the city. They are also responsible for the characteristic capricious road pattern, which follows height lines in order to keep gradients acceptable from a road-engineering point of view.

2. DATASETS AND METHODS

With the aim of producing maps in which Space Syntax, Spacematrix, Mixed-Use Index and property ownership data are combined, two new ways of visualising integration levels have been tested. This method goes further than the raster method introduced by van Nes, Ye and Mashhoodi (van Nes et al., 2012; Ye and van Nes, 2013, 2014) (see figure 1).

With the first method, the integration levels contained within the line segments are projected onto the building plots adjacent to these segments. This is achieved using an Overlay operation in ArcMap. The method is chosen because the building plots themselves contain the data that the integration levels are aimed to be combined with, i.e. the data on density and functional use as well as information on ownership of the plots.

The second method combines Space Syntax data with Spacematrix and the Mixed-Use Index with a buffer area around the line segments, since there are a number of inaccuracies in the initial results from the grid-based method. The overlay method works well for smaller plots, especially if they are connected to only one or two line segments. However, in particular on larger plots, values are found that often do not represent the actual degree of integration based on their position in relation to the street network.
The best example of this inaccuracy is the plot belonging to the goods terminal east of Bergen's railway station (figure 2). Directly connected to the globally and locally highly integrated street Strømgaten, this large plot thus receives a “highly integrated” classification. In reality, however, the plot is for the larger part flanked by line segments with much lower integration values than the map suggests. Moreover, the plot today is isolated and difficult to approach, and elongated to such an extent that only a limited percentage of people would approach it from Strømgaten, but most others from other streets located closer by.
Figure 2 - Global integration map projected on building plots
Figure 3 - Local integration map projected on building plots.
To avoid this deviation from actual integration values on larger plots, a buffer operation is tested out as a second method. With a buffer of 75 meter around each line segment, a surface area is created that contains the corresponding integration value of that segment.

To identify the segments with high potential for both to- and through-movement, the global and local integration values have been multiplied with each other and combined with the multiplied...
metric step depth values with both high and low radii. The result is an aggregated map that reveals the overall integration values based on the location in relation to the street network. In addition, the building function is visualised by colour according to the Mixed-use Index and simultaneously, the building height is indicated by the gradient of the colour in question.

3. RESULTS

In figure 2 and 3, the global and local integration values have been projected onto the building plots. The highest global values are found in the city centre area where there is an orthogonal street structure, introduced in the first decade of the twentieth century. The high values extend out of the centre along the main axis that leads past the Danmarksplass area. This axis has evolved over time by different road upgrades to facilitate the rapid growth of vehicle transport. Since 2009, Bergen's first light rail line runs parallel with the highway. The highest density and degree of function mix is found along this highway axis.

The orthogonal street network structure yields the highest local integration values in the city centre around the Smålungeren area (figure 3). However, there are no other local areas outside the city centre where equally high values are found. This lack is not only limited to the built-up slopes, where both the road structure becomes more parallel to limit the gradient and there is an edge effect, but is also found throughout the urbanised valley.

It becomes clear that the street pattern throughout the city (outside of the city centre) has been constructed for facilitating car traffic through the large topographic variations in the landscape. This has produced a curvier road pattern with fewer cross connections than in cities located in a flat landscape. Moreover, road engineers have the largest influence in Norwegian urban planning. In detailed land use plans, all new streets and roads are planned in detail, whereas the land usage along these streets and roads is merely indicated with a function and with a degree of building density.

Taking into account that Bergen’s street pattern is imposed on an extreme sloping landscape, the aggregated map in figure 4 was produced to reveal the areas with the best accessibility on both city level and local level, whilst including choice of route based on angular deviation. Again, the highest values are found in the city centre. Moreover, several main streets are well-integrated on a local level, such as Bryggen and Kong Oscars gate in the centre, Bjørnsons gate and Indalsveien leading up to Wergeland, Slettebaksveien and Hagerups vei north of Sletten, and Nattlandsveien as the main road on the east side of the valley.

These red areas are undergoing a considerable degree of urban transformation in terms of increased density of the built mass. Ground prices in these areas are rising. New building projects have larger floor space and more storeys than the old buildings. The amount of commercial establishments is also increasing. The trajectory of the light rail line has subsequently connected these centres with each other. Most areas around these centres, marked in orange, are relatively well-integrated, although further away, the values drop sharply.

As a test of the method, a close-up study was done of the area around Danmarksplass, an area that has developed incrementally over the last 80 years without any overall urban planning. The goal is to reveal how building density and degree of multi-functionality are strongly influenced by the degree of spatial accessibility of the street and road network. The local centre on Danmarksplass is located along one of the main routes leading towards Bergen centre.
Figure 5 shows the metric step depth analysis with a high metric radius combined with the degree of function mix. Here, the main routes through and between various neighbourhoods are highlighted. Where the values are high, the degree of function mix and building density are high. Schools, restaurants and shops are located along the eastern side of the busy highway as well as a light rail stop. The narrow pavement on this side of the road is always frequented by a high number of people.
The same features can be seen in the metric step depth analysis with a low metrical radius shown in figure 6. In particular, a high degree of function mix occurs on ground floors of buildings where the values are high. Local supermarkets, food shops and snack bars are located along these locally highly integrated streets. There is a cluster of local grocery shops and retail in a local centre west of Danmarksplass, which has the highest locally integrated street. These
shops predominantly serve local residents living in the vicinity. The connections for pedestrians and cyclists between the local shopping centre and the main centre in Danmarksplass, however, are poor. The highway through the area acts as a barrier and the two sides are only connected by two pedestrian subways. There are no pedestrian crossings on street level.

Figure 7 - Angular Step Depth From Public Transport Stops
Figure 8 - Functions projected onto axial lines
Serviced by a few bus lines, analysis of the angular step depth from public transport stops shows that public transport coverage is quite high in the Gyldenpris area west of Danmarkspluss. However, the transformation from a suburban to an urban district seems to be hindered due to a segregated street pattern and a low socio-economic status. In contrast, the Kronstadthøyden area on the east side is not locally serviced by public transport at all. The street pattern is more curved. Moreover, the neighbourhood has a higher socio-economic status than the Gyldenpris area. This difference is for a large part due to sun conditions. Whereas the Gyldenpris area is in the shadow of a mountain most of the day, the Kronstadthøyden area has good sun conditions. Some new developments are currently taking place in the Møllendal area to the northeast and the Haukeland area to the east.

As an experiment, the degree of function mix was projected onto the axial lines (figure 8). The correlation between functional mix and integration values seems strong. Amenities (coloured in blue), to which most non-residential functions belong, are predominantly connected to main routes. Offices tend to be located on the side streets of these main roads, ensuring favourable accessibility both by car and by public transport, whilst mono-functional residential streets are clearly clustered away from the main roads.

4. DISCUSSION OF THE RESULTS

It turns out that developments in Bergen city take place in line with the natural urban transformation process. Well-integrated streets have more to- and through-movement than poorly integrated streets. Shops and businesses cluster around these streets and densities increase considerably in comparison to the situation prior to the new situation.

Seemingly, cities in Norway are currently transforming on an “anti-urban“ track. Even though the intentions are to make compact cities, there are three drivers for urban sprawl in Norway. For the first part, urban developments are still steered by a strong emphasis on private car accessibility. New buildings are equipped with parking garages in the basement and often at ground floor level. As a result, building projects create poor urban qualities for pedestrians and cyclists. This stands in strong contrast with the municipality’s formal ambitions to reduce the growth of car traffic with 50% by improving the walking and cycling conditions in urban areas.

The second cause for the continuation of the anti-urban tradition is Norwegian property legislation. Although private property developments do result in space-efficient exploitation of building plots with high short-term profits, the flexibility and adaptability to adjust to changes on the long-term is lacking. Moreover, these private owners have the last word concerning the degree of multi-functionality. In addition, property owners tend to plan and build their properties to the current context rather than being future-oriented. Access from the public domain is hardly taken into account and private car accessibility is prioritised. Attitudes like these strongly affect the organisation of public spaces that link the properties to the public street network. Disappointingly, this often results in an incoherent, anti-urban structure with inward oriented buildings that lack active frontages towards the public streets.

The third aspect is the hilly Western-Norwegian landscape. Technical innovations now give way to previously impracticable or unrealisable plans, although they are expensive. Moreover, carrying out functional changes in a later stadium would be much more demanding. Therefore, any possible short-sightedness from private developers could produce a building stock that is hard or expensive to adapt to new uses.

The method of projecting integration values onto building plots can be a useful tool in Norwegian planning. By linking integration values directly to building plots, the authorities can take measures that oblige privately owned properties to be developed with the urban qualities related to accessibility for pedestrians, cyclists and public transport, flexibility, multi-functionality and, in the near future, energy production, smart communication and sustainable mobility means.

The second method, using buffer lines, is more usable to locate densification potentials based on the position in the urban fabric. In addition, this method allows for quick identification of areas...
that are segregated as a consequence of the street pattern layout. The municipality and road authorities can use this method as input for overall development plans as well as infrastructural improvements, and subsequently predict the effects on building density and degree of diversity of such plans and measures.

The test analysis of public transport stops as a backbone for densification reveals that the influence of bus routes is insignificant in comparison to that of the light rail. This might be due to the comparatively long-term character of light rail lines, creating a certainty of passenger flows along these routes. The municipality is currently developing plans for three new light rail routes aimed at improving the accessibility to and from the city centre to the districts further away. It can therefore be expected that redevelopments will intensify more along these lines than the integration values based on the street pattern would otherwise suggest.

5. CONCLUSIONS

How can this research be used to make recommendations for Bergen municipality on where and how to densify? Evidently, the street network configuration influences the degree of building density and degree of function mix. Four types of urban areas were identified based on street network integration on local and global scales:

Type A: High local and high global integration of the street and road network.

Where extra space becomes available, these areas can be transformed with a high density of built mass. This can include high-rise buildings. The aim is to provide land use plans that allow a wide range of different usages, in particular on ground floor level. Areas suitable for this kind of development in Bergen are the city centre, the harbour areas around the city centre, Danmarksplas and the old industrial area Mindemyren.

Type B: High local, but low global integration of the street and road network.

Where there is space, these areas can facilitate high density of dwellings with ground floor spaces for shops, small businesses and services. Depending on the local circumstances, high-rise buildings can be considered as an option. As an example, the Sandviken area has many 2-3 floors high old wooden houses. The type and style of buildings give this area a particular place.
character. New buildings will have to adjust to the existing building stock in scale and style to avoid damaging the place-identity of that area. Areas suitable for this kind of densification are the various local centres outside Bergen centre. Most of these small local centres are situated along the main routes leading through various urban areas. Areas located along the light rail also belong in this category.

**Type C: Low local, but high global integration of the street and road network.**

These locations are suitable for high densities of housing. Where possibilities exist to create a locally integrated street network, local shops on the ground floor can be facilitated. An example of such an area is the southern part of industrial area Mindemyren.

**Type D: Low local and low global integration of the street and road network.**

Where there is space to develop, high densities of only dwellings are desirable. These areas have a low degree of accessibility, and are therefore little attractive for shop owners. Examples of these kinds of areas are found around the lake Store Lundgårdsvannet such as Møllendalsveien, and harbour areas located along the fjord Puddefjorden.

Figure 9 shows the principles on how to densify. The colours in the diagram in figure 9 are applied in the combined integration map of figure 10, showing how and where to densify in one map.

Four groups were used in this inquiry. It is also possible to use nine different groups where high, medium and low values of global and local integration are combined. This would enable the application of more detailed strategies. In this case, however, being in the beginning stage of collaboration with the municipality and in a planning process where multiple NGO’s, property owners and stakeholders are involved, operating with four different categories rather than nine is more practical. In addition, the various densification strategies for each of the nine categories would need to be defined.

The experiments with the buffer line method are still in a test stage. The next step is to find ways to combine density, MXI and Space Syntax data into one buffer line model. The raster model is useful for overall strategic land use planning in whole urban regions or in regional planning. Professionals such as spatial planners and urban geographers may find this model useful. The polygon model is useful as a guide for urban designers and architects who work on plot level. Finally, the buffer line model can be useful for road engineers to make them aware of the spatial potentials of their planned road and street links. After all, the degrees of building density and function mix depend on the degree of spatial integration of the street and road network.
Combining Space Syntax with building density, land usage, public transport and property rights in Bergen city.

Figure 10 - Strategies for where and how to densify
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THE POST-SOCIALIST URBAN TRANSFORMATION OF TIRANA IN HISTORICAL PERSPECTIVE:
Mapping the ideological dimension of urban growth.

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ABSTRACT

In contrast to planned cities, where subsequent growth tends to occur mainly at the urban periphery, in contemporary Tirana this trend has been accompanied by the striking densification of existing neighbourhoods through the appropriation of previous public spaces. This transformation of Tirana’s built environment has occurred within a very short space of time during which the radically top-down urban planning ideology associated with the communist regime was succeeded in 1991 by an equally radical ‘bottom up’ model, characterized by mass urban migration and unregulated capitalism. This paper applies space syntax to the question of post-socialist urban transformation. It seeks to understand the extent to which the ideological dimension of morphogenetic processes in Tirana gave rise to distinctive patterns of growth.

Space Syntax has a rich tradition in historical studies of urban growth processes. Griffiths (2012) has identified four approaches to ‘spatial history’ (Griffiths, 2012). This paper’s approach is consistent with the second category, that of ‘syntactic growth processes’. The research made use of historical cartography and a contemporary aerial map of Tirana to produce a time-series of syntactic models which endeavours to explore the city’s growth processes from a configurational perspective. Four distinct historical stages are identified to represent the evolution of Tirana’s urban form through contrasting ideological regimes: 1921, 1937, 1989 and 2016. The GIS-based ‘cartographic redrawing’ method pioneered by Pinho and Oliveira (Pinho & Oliveira, 2009a, 2009b) has been adopted to systematically study Tirana’s morphogenesis, working backwards from the contemporary model to remove non-existent elements and readjusting to the changed shape of the urban fabric as needed. In presenting this research, the emphasis will be on the latter period as the prime focus is on the specific character of the post-socialist urban transformations of the city. On the basis of this analysis the research finds that, consistent with the arguments of Tosic (2005) Tirana’s expansion is consistent neither with the typical pattern of urban growth on a western model, nor even that of a ‘one size fits all’ post-socialist transformation (Tosics, 2005). On the contrary, its distinctive features must - in the first instance- be interpreted in the context of Albania’s twentieth-century history.
KEYWORDS
Tirana, post-socialist, informality, space syntax, network analyses

1. INTRODUCTION

Mapping and analysing Tirana’s growth under contrasting planning models and political ideologies is the main purpose of this paper. This objective will be achieved through examining four historic periods respectively, 1921, 1937, 1989 and 2016. The tool adopted to study the consistent urban development of Tirana is Space Syntax, hence the historic periods are drawn as axial representations from: a) historic maps (1921, 1937), b) hand drawn masterplan (1989) and c) GIS referenced high resolution aerial images (2016).

The case study of this work, Tirana, is introduced in details in the second section where information is given on the main political milestones that have been transforming the capital spatially. It begins with a brief introduction of the largest city of the country and continues with accounting for the reasons why the above mentioned four periods were chosen to represent the capital in our analyses. The third part sets out the methodological approach that was taken to accomplish this study, from the digitalization process of Tirana, to the introduction of space syntax as the main tool adopted in running the network analyses; both axial and segment analyses. The last two parts of the paper present some initial thoughts deriving from the spatial analyses and how the work intents to further develop taking into account the results at the city scale.

2. SPATIAL HISTORY

Consistent with the aim of this paper is to lay down how contrasting political ideologies and political circumstances have been influencing and shaping the spatial configuration of Albanian cities. We seek to understand the growth of Albanian cities from a spatial perspective at distinctly different social, political and economic models. In general terms, morphological histories are distinguished by a concern to understand morphological transformation in the social context of morphological ‘events’ – in the sense of historical occurrences with a direct bearing on the evolution of urban form (Griffiths, 2012: 6).

Through the case study of Tirana we want to shed light on the social logic of such processes, aided by the modelling of the configurational space itself. The spatial and ideological historical milestones have already been described in two previously published papers. Dino et al (2015, 2016) identified the main historical evolution of Tirana into a contemporary city, describing: development of the city through contrasting historical moments, historical context in a wider geopolitical perspective (the Balkans and Eastern Europe), how ruling political regimes affected spatial growth and what planning models have been implemented, morphological transformation, main forms of architectural styles, land use transformation and evolution of urban cultures. However, a brief summary of the most important historic events is presented in the following paragraph.

2.1 TIRANA CASE STUDY

Tirana has been a small town established around the 17th century, time when Albania was part of the Ottoman Empire. Until the beginning of the 20th century, Tirana was an organic town with narrow curvy streets and low rise buildings. The town had two main function which were sharply divided spatially, the centre was the socio-economic hub with the mosque and the bazaar whereas the rest of the built form consisted of purely residential units (detached houses) (Aliaj, 2003; Kera, 2004). Tirana became a city as it was claimed the capital of the country in 1920. There were several reasons that contributed to choosing Tirana as the capital of the country and some of the most important ones include: a) there were no foreign army bases settled around Tirana, b) Tirana was located at the center of the country, c) through the port of Durres it was closer to the outside world and d) Tirana was a town situated in a vast plain and could meet the government needs for new administrative buildings and residential
areas (Kera, 2004). First attempt to modernize Tirana was made during the rule of King Zog in 1923, when Austrian and Italian architects were contracted to design a masterplan for the city with contemporary features such as: wide boulevards, new square in the centre of the city, orthogonal road system with orthogonal neighbourhoods, wide streets lined with buildings of contemporary architecture and ring radial road network (Aliaj, 2003). The period to follow the end of World War II, was the beginning of nearly five decades of trueful Soviet style socialism. Prevailing city planning models included: abolishment of private ownership at all levels, introduction of zoning as concept, provision of social housing (mainly standardized mass production) and a mono-centric city model (Aliaj, 2003). The centre possessed the most distinctive characteristics and it was the focal point of all political, administrative, educational, and recreational activities of the whole city, whereas the urban edges consisted of agricultural lands and industrial sites. All public spaces where busy throughout the afternoon hours, with abundant pedestrian traffic which at the time was encouraged by the absence of private cars, notably low incidence of crime, daily cultural practices of visiting family and relatives or evening strolls, standardized work schedule across working force (7.00 am to 3.00 pm). However, what the totalitarian regime had constituted changed rapidly with its fall in 1991. Soon after, in early 1992, a new ‘trend’ of bottom up development emerged, giving rise to informal growth initiated by the citizens themselves. Privatization and the occupation of land and buildings opened the city to rapid development which was mainly reflected in: heavy traffic, construction of shops (kiosks), houses and squatter settlements (Felstehausen, 1999). In less than a decade Tirana’s metropolitan area almost tripled its population from 225,000 to 600,000 inhabitants (Felstehausen, 1999).

3. METHODOLOGY

The next section presents the application of space syntax approach in the evolution of Tirana’s growth during the last two centuries. Hillier and Hanson (1984) developed space syntax theory as a method that defines configurational attributes of street networks (systems) and relates them to patterns of use, social activity and cultural meaning (Hillier & Hanson, 1984). The advantage of implementing such an approach in understanding Tirana’s growth is that it allows for the consistent study of street networks across different urban scales, whilst it enables comparison among local and global structures. Hillier (2012) demonstrates that cities share two fundamentally similar structural characteristics (Hillier & Penn, 1996). The long lines are set against many short ones creating a background network of predominantly residential activity. While the foreground network is economically driven, facilitating movement through the city, the background network tends to impede movement and is culturally orientated, differing from city to city.

The analyses are split into two parts: the first part 3.2 includes axial analyses whereas the second part 3.3 looks at segment analyses throughout the four historic periods.

3.1 MAPPING URBAN GROWTH

The mapping of the four historic periods that have been analysed in this research have been drawn from three different kind of cartographic sources. The first two periods 1921 and 1937 have been drawn as axial representation of historic maps which were collected during field work conducted in Tirana. These two historic maps have been georeferenced and superimposed on ArcGIS platform and have been drawn in diachronic order, adding or erasing axial lines that did not exist during the earlier period or that were new during the later period, going backwards and forwards. As the four periods have a considerable inconsistency in regarding the road network among them, the first two periods when compared to the latter two periods, the cartographic redrawing method (Pinho & Oliveira 2009a, 2009b) has been utilized only for redrawing 1989 map from the 2016 period. The first axial map of contemporary Tirana was drawn from georeferenced aerial images superimposed with road center line map of 2007. All the axial lines were drawn individually rather than automatically converting the road center line
map and then simplifying the results. Randomly, across the city the road center line map does not reflect the reality of all paths and movement corridors. This is prominent especially, in areas consisting of apartment blocks built pre-1991 -originally designed with vast public spaces-that have been built up (after 1991) creating new movement patterns that have accommodated for the changes. As illustrated by Figure 1, in frequent cases there are urban situations (such as parked cars) that inform on where paths should be going through even when not flagged in the road center line map. The ratio of officially mapped road network (road center line) versus actual (physical) road network -as it can be observed though a very random case presented in Figure 1 - is significantly high. This means that an unrealistic scenario that barely reflects the movement flow of Tirana is being used as an official dataset. Situations like this reflect the chaotic situation of postal addresses in Albanian cities through the post-socialist transition periods; where rather than a full address (only the ones that have been built after 1991) landmarks have been used as referral points.

Figure 1 - Road center line map overlapped by axial line map.

The excellent quality of the aerial maps has allowed for maximum clarity when zooming in at a local scale throughout the city, and has eased the task of counting for all existing routes. However, this cannot be said for both periods as the earlier period (1989) visibly differs in quality when compared to the aerial images. The hand drawn masterplan of Tirana is the only cartographic source that could be collected envisaging the built form during the socialist period. Unfortunately, it is in poor condition with several disproportional, blurry or even missing information areas. Hence, it has been a challenge to redraw this map due to lack of clarity in regarding crucial morphological information. Besides graphic imperfections caused by scarce quality of scanning, the masterplan itself has an array of configurational issues. For instance, plot boundaries were not always drawn using the same rules, the scale of the buildings is not consistently drawn for all units, also paths and streets were not highlighted in all cases. Thus, assumptions have been made when necessary in drawing the axial representation of movement network across the city. The rationale behind the assumptions consisted of constantly checking with the paths of the 2016 map, also when the possibility was presented discussing it with locals who do have a good memory of 'what' was 'how' before. All possible ways of representing the most accurate information as an axial representation of the historic road network have been
exhausted – this to ensure reliable and close to reality environments which than could be thoroughly analysed.

3.2 AXIAL ANALYSES


Tirana’s analyses have been carried out with Depthmap software, across the four historic periods this research sets to study. The analyses presented in this paper compromise global (radius n) and local (radius 3) integration, connectivity, global and local intelligibility and synergy. Through this set of analyses we wanted to shed light on how these syntactic component values have been changing through contrasting political regime styles at two different scales, both at global and local scale. Table 1 provides a synthesis of the average metric and axial parameters of the chosen historic periods.

Through global integration we seek to understand the relative depth of each axial line in regard to all other lines in the system. At a local scale, integration can express the level of accessibility up to three steps away. Intelligibility, on the other hand, expresses the degree of linear correlation between connectivity and integration, which can be defined as the integration of each space into the system as a whole- the degree to which what we can see and experience from the spaces that make up the system and what we cannot see. Finally, synergy indicates the degree of linear correlation between local and global integration. Figure 2.1 shows the evolution of the urban layout of Tirana from a small town (1921) to the largest city and at the same time the capital of the country (2016), overlaid on a single diagram.

<table>
<thead>
<tr>
<th>Map</th>
<th>Number of Lines</th>
<th>Line Length</th>
<th>Global Integration</th>
<th>Local Integration</th>
<th>Connectivity</th>
<th>Global Intelligibility</th>
<th>Local Intelligibility</th>
<th>Synergy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1921</td>
<td>595</td>
<td>156.961</td>
<td>0.695</td>
<td>1.361</td>
<td>2.661</td>
<td>0.261</td>
<td>0.511</td>
<td>0.511</td>
</tr>
<tr>
<td>1937</td>
<td>1274</td>
<td>93.251</td>
<td>0.872</td>
<td>1.435</td>
<td>2.539</td>
<td>0.343</td>
<td>0.565</td>
<td>0.608</td>
</tr>
<tr>
<td>1989</td>
<td>4672</td>
<td>114.947</td>
<td>1.022</td>
<td>1.79</td>
<td>3.285</td>
<td>0.311</td>
<td>0.545</td>
<td>0.571</td>
</tr>
<tr>
<td>2016</td>
<td>14,619</td>
<td>83,004</td>
<td>0.561</td>
<td>1.373</td>
<td>2.464</td>
<td>0.228</td>
<td>0.557</td>
<td>0.409</td>
</tr>
</tbody>
</table>

Table 1 - Tirana’s metric and axial parameters: 1921-2016

Tirana’s axial system of 1921 is constituted by 595 lines with an average length of 157m. During this period the average global integration is 0.695. An interesting fact about the main integrator, ‘Rruga e Dibrës’ (1.137), of the system is that it is one of the three street that it still part of the road network of contemporary Tirana, and actually it has almost the same configuration. The average value of local integration (radius 3) is 1.361 with an average connectivity of 2.661 where the most connected line is one of the radial routes around the historic city core (the bazaar). The rest of the roads have perished along the upcoming historic periods. The local structure of the city system in 1921, regarding synergy, has the value of 0.511 which seems a reasonable correlation among local and global integration. Regarding intelligibility, the values reveal how the old town of Tirana performed far better at a local scale where the average value of the...
During the second historic period that of 1937, the axial system has doubled the number of lines to 1274, whilst the average line length has dropped to an average length of 94m. The main integrator of the system is ‘Rruga e Barrikadave’ (1.522), which directly connects with three other lines presenting highest values of integration, followed by 5 orange lines and finally the lowest level of integrators it connects to are short yellow lines along the eastern side. Both global (0.872) and local (1.435) integration average values have increased. Traces of major planning interventions are reflected in this axial system, with more grid-like orthogonal structures especially on the far southern part of Tirana. At this period Tirana is at the early stage of transforming into a ‘real’ city. Due to the fact that this is the very beginning of implementing the regulatory plan of Tirana, there is still low amount of connectivity among the old and the new parts. The new parts are at the building out stage, hence resulting in a slight decrease of the connectivity value of the system to 2.539. The top-down interventions during the 1930’s, resulted with a good improvement both in local (1.435) and global (0.872) integration values and did increase the synergy of the system to 0.608 which results the highest linear correlation between local and global integration from the four study periods. Intelligibility is another parameter that is the highest among all the historic periods during 1937. At this stage the average local intelligibility is 0.565 whereas at the global scale it scores an average of 0.343. It must be said that during this period the integration of each space into the system as a whole is considerable, to the point that it is higher even than the average contemporary European cities figure of 0.266; assuming that it must have made the city ‘legible’ at this point in history (Hillier, 2002).

1989 represent a period by when all the centralized planning regulations had been implemented fully and it constitutes the ‘compact’ socialist Tirana. Structurally, this is the ultimate layout of the capital before it started to have any bottom-up interventions. This system is made up of 4172 lines (which is about of the average of the UK cities- just 8% less) with an average line length of nearly 115m. During the socialist regime, the city was perceived as a monocentric structure (core of the city) with ‘satellites’ that provided workplaces (industrial sites) sparsely with residential units around the factories. That is how it can be explained that the axial system has the longest average line length. Mostly due to the fact that these satellites had to be connected with the core, mainly with continues long (axial) lines. Connectivity and integration at both scales too, have the highest average values during this period. Respectively, connectivity has an average value of 3.285, local integration 1.790 whilst global integration scores an average of 1.022. However, there are measures that have a slight decline in values when compared to 1937 system. Intelligibility at both scales has dropped, at the local scale the average is 0.545 whereas at the global scale the average figure is 0.311. Even though both local and global integration values have increased, the synergy of the system still managed to decrease; this due to the fact that the gap between local and global scale has increased where the system has ‘improved’ more locally rather than globally. Perhaps, a good explanation could be that during this period society was barely living in a motorized era and everything was accessible through walking.
In 2016 Tirana’s axial system is constituted by 14,619 (2.9 times more than the average European city) which have an average length of 83m. The number of axial lines has been remarkably increasing from study period one to period four. This kind of dramatic increase in line numbers can be interpreted through the bottom-up initiated growth processes. Growth happened in an ad-hoc style, and the inhabitants who were primarily the ones initiating these processes, built wherever there was a potential for occupying ‘public’ space. So rather than, extending orthogonally or linearly existing streets or neighbourhoods, the process of accommodating the street to the dwelling became a dominant way of building customs. Arguably as a natural consequence of prevailing building modes, global integration almost halve to 0.561 which is the lowest figure of all the historic periods. In fact, this phenomena is legible bare-eyed by just observing the axial model. The model has not only grown (sprawling) towards the extremities, but it has densified its road network on the inner core of the city (what is visible in 1898 historic period). These intensifications have occurred as short lines, predominantly deepening the system with many to-routes consisting of more than three steps away per origin. In this situation the dark blue lines have essentially grown in number, affecting the relation (and performance) of each axial line in respect to all other lines in the system. Regardless, the huge impact the informal growth processes have had at a global scale, local integration has not been affected that greatly. The 2016 Tirana system has an average value of 1.373 for local integration; which is pretty much an average figure across the four periods but rather low if compared to European cities (2.254). Other parameters that reflect the lowest values across the study periods at the 2016 system are connectivity 2.464, global intelligibility 0.228 and synergy 0.409. In the set of lowest performing parameters we do not see local intelligibility, though. But again, it does make sense as the system has been able to build a strong local network, where the bottom-up processes have been driven by local needs and have been catering for the local needs.

Finally, we could say that for all the compared parameters Tirana is somewhere between the UK and Arabic cities (see Hillier, 2002). Where for certain parameters the system performs closer to the UK cities and other the values are more congruent with those of the Arabic cities.
3.3 SEGMENT ANALYSES

The main two measures that space syntax uses for segment analyses are ‘integration’ and ‘choice’ at different kinds of distance (topological, angular and metric distance) and radii. Usually, for urban a scale, the radii varies from 400m (walkable distance) to 10000m, 30000m up to N(global, meaning the entire system). However, for the case of Tirana, the presented radii results compromise 400m, 800m, 1000m, 2000m and radius n. The reason for not choosing any larger radii between 2000m and radius n is due to the fact that Tirana within the municipality borders throughout the historical stages does not justify picking larger radii’s at all times. During the first two study periods, the city’s diameter was about 4000m. Hence, any metropolitan area radii figure would not be sensible to run.

In an urban situation through ‘integration’ we can assess accessibility measuring potentials of to-movement, whilst ‘choice’ indicates through- movement between any pair of origins and destinations. For the results to be comparable, the measures have been normalized to Normalized Angular Choice (NACH) and Normalized Angular Integration (NAIN) (Hillier et al, 2012).

<table>
<thead>
<tr>
<th>Map</th>
<th>Number of Lines</th>
<th>Segment Length (m)</th>
<th>Normalized Choice NACH</th>
<th>Normalized Integration NAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>R=400m</td>
<td>R=800m</td>
</tr>
<tr>
<td>1921</td>
<td>1238</td>
<td>68.165</td>
<td>0.812</td>
<td>0.972</td>
</tr>
<tr>
<td>1937</td>
<td>2605</td>
<td>41.440</td>
<td>0.824</td>
<td>0.819</td>
</tr>
<tr>
<td>1989</td>
<td>10664</td>
<td>41.000</td>
<td>0.934</td>
<td>0.928</td>
</tr>
<tr>
<td>2016</td>
<td>27300</td>
<td>40.114</td>
<td>0.847</td>
<td>0.835</td>
</tr>
</tbody>
</table>

Table 2.1 - Tirana’s metric and NACH parameters: 1921-2016

<table>
<thead>
<tr>
<th>Map</th>
<th>Normalized Integration NAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R=400m</td>
</tr>
<tr>
<td>1921</td>
<td>1.283</td>
</tr>
<tr>
<td>1937</td>
<td>1.057</td>
</tr>
<tr>
<td>1989</td>
<td>1.107</td>
</tr>
<tr>
<td>2016</td>
<td>0.957</td>
</tr>
</tbody>
</table>

Table 2.2 - Tirana’s metric and NACH parameters: 1921-2016

The number of lines (segments) has incrementally grown from period one to period four. The ratio of weighted segment number increase reaches its peak during the last stage where the segment’s number grows from 10664 to 27300. The increase in segment numbers has been accompanied with a decreasing segment length from 1921 69m to 2016 41m. Table 2.1 and Table 2.2 reveal that to-movement and through-movement potentials are the highest consistently, through all radii’s during 1989 except for NAIN R400m where the highest to-movement potential can be found in the 1921 system (see Table 2.4).
If we want to compare overall performance potential across periods, the analyses suggest that in terms of spatial configuration the city had better chance of performing in 1989—a period when cities were strictly planned. However, if we combine spatial structure (configuration) with other aspects of society such as urban life and economic development, period four gives rise to the fulfilling these necessities. As soon as the top-down planning model relieved its ‘pressure’—associated by the fell of the socialist regime—, the self-regulating processes begin to intervene in the socio-spatial structure of the city. As all these bottom-up interventions were not regulated to any extent, random growth structures started to emerge. In the first two decades of post-socialism these self-regulating interventions have been mainly economic driven. No planning regulations, development restrictions nor capacity studies were coordinating growth in Tirana (see Figure 3.1 for urban growth of Tirana, visualizing global radii NAIN and NACH analyses). Subsequently, the results are visible not only as part of overall social dissatisfaction but also, ultimately it is part of the results of the configurational analyses (see Table 2.1 and Table 2.2 to sense decline in movement potential). Besides the discontentment’s that relate to lack of infrastructure, public engagement and services, Tirana is a hardly legible city. Tourists and visitors often find it hard to move in the city and find their destinations, and it is an even harder task to accomplish to be able to go back to an origin point in any of the organically grown areas of the cities.

Table 2.3 - Tirana’s NACH 1921-2016

Table 2.4 - Tirana’s NAIN 1921-2016

Figure 3.1 - NACH and NAIN at RN for: 1921, 1937, 1989 and 2016.
In order to visually clarify the description of how growth influenced emerging structure in the case of Tirana across all study periods, Figure 3.1 shows a zoomed in part of the city at NACH R800m. The reason why this radius was chosen to represent through-movement relates to the fact that -regardless of Tirana’s sprawl and a society that is heavily motorized- walking to routine destinations is still an essential part of daily life. There are two things that can be observed by just carefully comparing across the periods. First, the structure has been consolidating towards a more orthogonal grid until period three (1989). Second, relates to values of through-movement potential, where a substantial transformation of light blue lines to dark blue lines has occurred from 1989 to 2016.

4. SYNTACTIC GROWTH PROCESSES

Hillier argues that historically, city centres not only grow and shrink, but also shift and diversify and with growth to large town or city level, a whole hierarchy of centres and sub-centres usually appears diffused throughout the settlement (Hillier, 1999: 107). Consistent with this argument, our analyses show that in Tirana a new structure of centres and sub-centres arose, mainly as a consequence of the bottom up planning culture. As a matter of fact, this can be supported in particular during the fourth historic period (2016) when numerous new centres and sub-centres have been organically spreading across the city allocated naturally as part of the informal process. Karimi (1997) in his research on organic cities has identified that such urban environments tend to maximise the integration of the centre in order to accommodate prime urban activities, whilst trying to reduce segregation of the city from outside and the rest of the city from the centre through expanding major routes (Karimi, 1997: 14). In the case of Tirana what is noticeable from the syntactic analyses -in particular if we look at the axial analyses throughout the study periods-is that global measures have been fluctuating up and down with significant decrease in 2016. Since the cease of the top-down planning interventions, the system has testified a great amount of interventions in its orthogonal structures with short, multiple step lines spread persistently across existing neighbourhood (block) structures. This has contributed to the increase in global depth of each line in respect to all other lines of the system. At the local scale, however, certain measures such as intelligibility or integration have changed at a lower rate –with no significant transformation during the post-socialist period. Karimi’s (1997:15) claim that ‘deep analyses of organic structures can reveal the principles and laws of urban growth which are based on an evolutionary fulfilment of the inhabitants’ needs during the process of spatial formation’ can be clearly observed likewise in the case of post-socialist Tirana.
5. CONCLUSIONS AND FURTHER WORK

We have been able to present a few findings about the evolution of the urban network in regarding local and global, to- and through- movement potentials. The aim of this paper has been only to compromise analyses of road network evolution. Assessing morphological transformation of the built form as a co-existential part of this growth process is planned as future work.

Hillier et al (2007) have noticed that at each scale there is a natural areaisation of the city into a patchwork of spatially distinguishable zones (Hillier et al, 2007: 275). Further step would be to identify morphological patters established by a rigorous study way. Even though patterns are not necessarily significant in all urban situations argues Marshall (2005:34), they do exist as a variable alongside others and should be taken into consideration. Samuels (2008:58) expresses that typomorphology can be used for managing change of inherited urban form. Additionally, in the other direction it can inform innovations with a clear idea of the structure of what is introduced and how it fits into the wider structures and processes’ (Kropf, 2006: 73). Further, in depth analyses and their rationalization can help in understanding the complex urban situation of post-socialist Tirana. Rigorous configurational and morphological studies should be able to ease and aid future decision making in regarding city scale planning interventions.
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ABSTRACT
Tobler’s (1970) First Law of Geography states that nearby things are more related than distant things. In other words, there is a close relationship between nearby things compared to distant things. This also implies that built form is in a relational process in its topologic embodiment and the overall spatial form emerges a certain degree of wholeness. Mediating C. Alexander’s (2002-2005) “levels of scale” property as a morphologic translation interface and using Shannon’s Entropy (1948) concept as a data-mining method, this study allows revealing the degree of uncertainty and disorderness that a certain spatial complexity embodies. Shannon’s Entropy, a method of measuring the information, has been employed in this study in measuring the state of uncertainty and disorderness conveyed through the multi-scalar context of built configuration across scales. Results have been hypothesized to correlate to the degree of wholeness, in other word completeness, of the case built area. Beyazit Square with its 50 hectare environs in the Peninsula of Istanbul has been selected as the case area due to the remarkable change that the square experienced through a harsh urbanization over the last sixty years. Building footprints belonging to two time periods have been used as raw data. Multi-scalar analyses conducted upon the data of 1946 and 2013 revealed that the wholeness of the square has deteriorated, almost halved, from 0.32bit to 0.63bit entropy level within last sixty years. This finding is being verified by the remarks of the spatial assessments done for the square and visualized by entropic interaction way of spatial modelling.

KEYWORDS
Wholeness, completeness, entropy, change, relationality

1. INTRODUCTION
It is due to our cultural context, maybe even due to our natural state of being alive, that we admit more value to life than a machine. We are biased. The distinction between machine and life boils down to the question of reproducibility. Only because we humans can dis- and reassemble a car makes it a machine? Is it too simple to be a system that has more value than the sum of its parts? The reason why a living organism is dead when disassembled and does not come to life anymore when reassembled is that first; we’re not able to disassemble without destroying it and second; living organisms, like ourselves, can be seen as an ongoing self-maintaining process. Once stopped, it would need to restart from the very first cell division to become alive again. That’s how we actually reproduce ourselves. Mehaffy and Salingaros (2011) state that
there is no way to decompose an organism into its parts without destroying the connective networks -subsystems- that make the whole system work.

There are pros and cons of applying the notion of a “living” and therefore biological organism to a city. One concern to point out here: Similar to biological organisms can’t we reassemble a city? Practically, we can! The “city life” wouldn’t be exactly the same as before, but there would be a life. Even in a city that has not been destroyed and reassembled, public life changes every day. Therefore, there is a loose relationship between wholeness and life. The notion of wholeness is too closely tied to the concept of life. It has been asked at what point a human being mentally and physically conceives itself as a whole. There are so many ways of being incomplete as a person and still being alive, that the entire question of wholeness is a large, flexible and not so clear phenomenon. In the middle ages a city without basic elements such as a wall protecting it, was not a city. Then the entire definition of spatial wholeness and so the notion of “living structure” appears to be a matter of time, space and cultural relevancy.

By all means, the question of “city as a matter of wholeness” will not make any common definition for everyone since it is not as purely intuitive as Alexander suggests. Even a catalogue of the 15 properties that Alexander structurally defines for his definition of wholeness doesn’t sound complete. It becomes misleading when conceiving wholeness as a solely physical property. Either spatial or functional, wholeness, as an urban spatial quality, requires a comprehensive looking on physical, cultural and mental everything what makes a “city”. Therefore, questioning the notion of wholeness out of two-dimensional spatial data, through referencing Alexander, seems formally correct yet a highly debatable attempt.

Place is an adaptive cultural process. It may be incomplete or imperfect and yet can have a life. Adapted to spatial analysis, the question might be phrased as: how whole or how complete is a space or an area based on the information conveyed through its various, multi-scalar, morphologic possibilities? Shannon’s entropy (1948), (2001) as a measure of uncertainty for conveyed morphologic information, is a consistent way to apply as the core data mining method in this study.

1.1 THEOREY OF WHOLENESS

Alexander’s overall idea of wholeness and life stands on a strong assumption of completeness. The wholeness of a built system is not about the quality and behaviour of each single entity what Alexander calls “centre”, but about the way they come together and therefore make each other strong across scales. This implies an emerging and holistic sense of completeness about the relative size, shape and density of centres in making a greater whole. This was one of Alexander’s major questions to himself in seeking of any structural features that tend to be present in those systems with more life (Alexander, 2002-2005, p. 144). He thinks that everything that has wholeness has also life and vice versa. Yet, the question arises around the need for a quantifiable definition of wholeness. It is obvious that Alexander’s definition of wholeness as a phenomenon is highly related to the concept of order. Yet, this is not a shallow understanding of order that only exists in the nature but a quality that may exist in everything.

At the end of intensive studies on the phenomenon of wholeness, Alexander distilled fifteen structural features that he thinks are the ways every possible sub-component in a system, he calls centres, come together and make each other strong so that the whole system generates a certain degree of wholeness and life. Alexander’s fifteen properties of wholeness are (1) levels of scale, (2) strong centres, (3) boundaries, (4) alternating repetition, (5) positive space, (6) good shape, (7) local symmetries, (8) deep interlock and ambiguity, (9) contrasts, (10) gradients, (11) roughness, (12) echoes, (13) the void, (14) simplicity and inner calm, and finally (15) non-separateness (Alexander, 2002-2005, pp. 244-289). Properties are the elaborative explanations of observations that were recorded in Timeless Way of Building (Alexander, 1979, p. 242). A “property”, as a relative quality, in Alexander’s texts, is a fundamental informative characteristic for wholeness and life (Waguespack, 2010). Alexander in this respect states that 90% of our human feelings are shared, and idiosyncratic parts which vary from people to people only account for 10% (Alexander, 2002-2005) and claims that human feeling is a legitimate
instrument for recognizing the wholeness. However it is still intuitive and pseudo-scientific which yet needs scientific confirmation (Marshall, 2012).

In order to understand “levels of scale” property in a comprehensive way, one may observe how an electric discharge in an electric field motion occurs and vanishes in a rush to recreate itself as in Figure 1. There is a recursive behaviour that repeats and brings itself into a new order through strongest to weakest zones in an everlasting way. Levels of electric zones create gradients and echoes through alternating repetitions as the integral parts of a robust whole. Alexander notes that it is not hard to see that in any system where there is a good functional order, there is also a good spatial coherence with a legible hierarchy (Alexander, 2002-2005, s. 246). In such hierarchy, the interplay among one level or size tends to be in a topo-geometric relationship with the nearest structural context. Tobler (1970) in "First Law of Geography" states that nearby things are more related than distant things. In other words, there is a close relationship between nearby things compared to distant things. This also implies that built form is in a relational process in its topologic embodiment and the overall spatial form emerges a certain degree of wholeness.

A structural complexity can be more or less alive depending on the degree of wholeness it has (Alexander, 2002-2005). Early major attempts to measure the wholeness of things or systems analytically were “Gestalt Psychology” (Köhler, 1947) and “Quantum Physics” (Bohm, 1980) in which wholeness mathematically is defined as a recursive physical structure. Alexander (2002-2005) in this respect noted that there was no mathematical approach at that time to unearth the meaning of wholeness embedded in things and reflectively in human psyche (Jiang, 2017). In brief, Alexander described wholeness as a phenomenon in profound details and widest perspective that no other approach has done before.

2. DATASET AND METHOD

Alexander’s assertions require scientific confirmation and this study raises the question of whether or not we can analytically measure Alexander’s definition of wholeness or completeness using “Shannon’s Entropy” (Shannon, 1948). In other words, this study develops a mathematical model of wholeness through generating the entropy for particular pixel levels out of building...
footprints raw data. Scale level in the proposed method refers to the varying pixel categories in data-mining. Scale in this kind of information retrieval process acts as a dynamic grid interface with equally divisible units upon any area’s raw data. Size of the grid units are dependent on the number of pixels that are framed for each scale level as seen in Figure 2 below. In other words, for each scale level, the area is overlaid by a different grid in which each equivalent unit frames a different pixels density and thus a different morphologic formation. Eventually, in each scale level, through varying morphologic formations framed by each unit, varying entropy values are calculated throughout the grid as in Figure 2 below.

This study, using Shannon’s information entropy theory, develops an alternative quantifiable approach that can measure the contextual nature of completeness for a built environment from the scale levels point of view. In order to achieve it, a spatial analysis tool has been developed by using two major programming languages; “C#” developed by Microsoft (2015) and “Processing” developed by Ben Fry and Casey Reas (Jones, 2010). The tool has two major functions: 1) Data-mining and 2) Data-visualization. Data-mining function has been developed by compiling diverse image processing algorithms on C# to retrieve data via a hybrid feature extraction algorithm out of building footprints’ raster data. Data-visualization function visualizes the retrieved data sets and illustrates the outcomes of the analysis. For this case analysis, building footprints vector data, for 50 hectares (500,000 m2) urban areas with 1024x1024 pixels resolution, has been selected as raw data. For two different configurations belonging to two different time periods, 1946 and 2013-, as seen in Figure 6, two different cumulative Entropy-IQR values have been generated via 10 different grid scales.

Statistical entropy was first introduced by Shannon (1948), (2001) as a basic concept in information theory, measuring the average missing information on a random source (Jat et al. 2007). Shannon’s entropy originated from information theory as a measure of uncertainty of conveyed information over a noisy channel (Bailey, 2015), (Jat et al. 2007). The larger the value of Shannon’s entropy, the higher is the uncertainty of information conveyed. Shannon focused on how to minimize the loss of information in revealing a message in another point. Entropy (H), in this sense, is a measure of information. H is dependent on the number of information categories, K. Higher the amount of data categories conveyed by an information, less probability of the same type of category to gather. It is also the least predictable state (Bailey, 2015), (Waguespack, 2010). Therefore, the entropy is always towards most probable or most likely state. By the same logic, the higher the spatial entropy, the more the uncertainty is, hence a larger potential towards change. Bailey (2015) states that Shannon’s entropy is content-free and can be applied to measure any type of data with a multiplicity of information. Shannon entropy is a quantity measuring the relations in a data category. Use of logarithm makes this quantity growing linearly with system size and “behaving like information”. Shannon in his original paper states that the logarithmic measure is more convenient since it
is mathematically suitable in measuring the number of possible states in which a system can be found. The unit of entropy is a “bit” (Wang, 2016). As it is distilled from diverse definitions of wholeness and Alexander’s assertions (Alexander, 2002-2005, s. 64, 72, 77, 78, 112, 122, 144, 145, 146) it is possible to say that low entropy implies a relatively higher degree of wholeness (Shannon, 1948), (Leibovici, 2009).

Starting from Alexander’s views on wholeness, the ultimate purpose of this study is to develop a mathematical model to unearth the degree of spatial uncertainty of a particular built area in relation to its immediate context. Using entropy in this sense, helps measuring the complex and multivariate information of two dimensional morphologic layout conveyed through the units of a grid system superimposed upon the analysed area. Entropy (H) by definition is a configuration-dependent concept. It is the measure of uncertainty that each unit holds considering of eight adjacent units’ total built probability (P) as illustrated in below Figure 6. G is the built probability specific for each unit area, while the entropy is generated for the units that are adjacent to eight units, as illustrated in Figure 6 below. In brief, H is a measure emerged through the relative morphologic state of adjacent unit areas.

Recent studies (Karlström & Ceccato, 2002), (Li & Reynolds, 1993), (Li & Huang, 2002), (Maitre, Bloch, & Sigelle, 1994), (Tupin, Sigelle, & Maitre, 2000), (Claramunt, 2005) about use of information entropy in measuring the multivariate distribution of spatial co-occurrences is progressive (Leibovici, 2009). When reviewing the previous research on this field, the core struggle that emerges is about generating the entropy for the same context yet with different spatial configurations. Leibovici (2009), in this respect, notes that there is still a need for a coherent methodological approach that will consider the relatedness of constituting elements as an adjacency factor among the analysed data category.

Advancing the aforementioned progress on measuring the entropy of spatial complexities, this study develops a progressive approach. Referring to Leibovici’s (2009) suggestion, the method is built on the ability of considering the nearness and relatedness as adjacency factors among the analysed units of various grid scales. As seen in Figure 2 above, the tool developed for this research enables running the analyses for various scale levels. For the case study in this paper, the analyses have been conducted for the grid scales from 1/100 to 1/1000 with regular intervals of 100. The way each single unit interacts with its eight adjacent units mathematically accounts in the calculation of entropy for each unit area except those by the grid edges. This leads to create a kind of highly varied data with varying spreads or deviations. In order to measure it, the multivariate nature of such data requires a discretization to eliminate the divergences.

IQR (Interquartile Range) is a statistical data measuring method that does a discretization for the data with varying spreads. It arranges the values from the smallest to the biggest. For discretization of the deviations along the data, IQR plays a role to extract the “middle fifty” where it draws a specified data as graphed using the Box and Whisker Plot in Figure 3 below. The extremes of the data are eliminated and it is where the bulk, middle fifty, of the data falls into. It is preferred over many other measures of spread in statistics when reporting about multivariate data sets. Due to fact that each output is scale-dependent, the ranges of the quartiles change as the scale of the analysis changes. In other words, each IQR for a specific scale relies on the changing morphologic states that are framed by different size of grid units. By the IQR method, each output data is reduced to a single value. Multiple analyses for varying scales allow generating multiple IQRs. Total sum of Entropy-IQRs that have been generated for diverse scale levels give the final outcome of the analysis.
Referring to Shannon’s entropy as formulated in below Equations 1, 2 and 3, for the ith unit of n units grid system, Gi is the unit-specific built portion where Pi value, considering the eight adjacent neighbour units’ G values, is a relative value for built probability considering the adjacent units. Hi is the entropy for the ith unit and it is calculated as long as the unit is adjacent to eight surrounding units as seen in Figure 4 below. In other words, the units by the grid edges are exempted in entropy calculation.

\[
G_i = \frac{\text{built portion of pixel } i}{\text{total pixel area}}
\]  
\[
P_i = \frac{G_i}{\sum G_i}
\]  
\[
H_i = P_i \cdot \log\left(\frac{1}{P_i}\right)
\]

Equations 1, 2 and 3: G, P and H Calculations Using Shannon’s Entropy

Each grid unit in Figures 6 and 7, matches a particular space and thus a particular portion of morphologic occurrence represented by a G value. Algorithm assigns G=0 when the unit area is totally unbuilt, and G=1 when it is fully built up. Entropy (H) for the non-edge units, those interact with eight immediately adjacent ones, as in below Figure 6 are calculated. Unit number 5 in Figure 6 below is being surrounded by 8 adjacent units. The entropy (H) for the unit with G5 built density value is calculated by considering G5 with G1, G2, G3, G4, G6, G7, G8 and G9 values.
In interpretation of IQR, knowing the values of quartiles, Q1 and Q3, has critical importance. Position of the quartiles, between 0.00 and 1.00, can be highly distinct, somehow close to each other or juxtaposed which at the end explains how the IQR is created in fact. When the quartiles are located distinctly far from each other, IQR gets a higher value. This also points to the deviations that exist along the entropy dataset. The deviations in the dataset point to the remarkable differences among the morphologic formations framed by the grid units, in other words among the G values, unit based built probability, of the grid units. The differences gradually affect the aforementioned P value in equation 2 above, the relational probability of 9 connected units as seen in Figure 4 above, and thus the entropy (h) value in equation 3 above.

In brief, the positions of lower and upper quartiles give information about the general morphologic character of the analysed area. Approximate Q1 and Q3 values explain that there is a recursive, proportionally continuous, built pattern in the analysed area. Analyses that are performed via grids with varying scale levels, do not necessarily effect the G values and thus the P and H values significantly in a continuous built context since the quartiles keep staying recursively approximate or juxtaposed. This kind of scrutiny, using the proposed method, helps to understand that any certain continuous and legible spatial order, no matter how it is configured, most possibly generates approximate or juxtaposed quartiles and thus a lower h-qir value as an indicator of higher wholeness.

Correlation between the degree of wholeness embedded in the very spatial order and the feeling of wholeness revealed deep inside human being requires another research since the sense of wholeness is about complex agglomeration of manifold constituents that address intuitions. Without doubt, Alexander never ignored functional, socio-cultural and architectural content in describing spatial wholeness yet it reminds the question of whether or not his 15 properties always grant a certain level of wholeness in real space.

2.1 BEYAZIT SQUARE AND ITS EVOLUTION

Beyazit Square was, and is, one of the most historic and symbolic squares of Istanbul Peninsula, throughout the history. The square exists on the third hill of the Historic Peninsula (Freely, 2011, p. 183). The historical significance of the square dates back to Roman period and known as Forum Tauri and Forum Theodosius in Byzantium period (Ayvazoglu, 2012) (Müller-Wiener, 2002). The square exists in the very intersection of significant urban elements that make historic Istanbul image.

Beyazit Square experienced a serious demolishing interventions from the mid-20th century onwards urbanization resulting in a vast destruction of the existing built city form. Scholars (Müller-Wiener, 2002), (Eyice & Kuban, 1993), (Ayvazoglu, 2012) note that the most destructive intervention upon the square occurred in 1950’s through the implementation of the Prost plan, which gave priority to the motor-vehicle traffic. The enlargement and downing of the Ordu Street in the south bound of the square resulted in not only a massive fragmentation between the street and the square, but also a remarkable change in the adjacent built environment of the square. In addition the Northwest access of the square, Vezneciler Street was also enlarged through a vast amount of massive destruction as shown in below Figure 5. Today one can still recognize the remaining parts and the fragments of the historic buildings on the site as seen in below Figure 5 street views (IMM, 2012). Today, the architectural elements that make the square’s identity are foremost the Istanbul University’s main gate, the Beyazid Mosque Complex, the State Library of Beyazid and the Madrasa(Ayvazoglu, 2012). Spatial assessment reports that have been developed by the Metropolitan Municipality of Istanbul (IMM, 2012) and by the Protection Board for Cultural Assets (2013) point out to the poor spatial organization of the square due to remarkable change that the square faced within the last decades.

3. RESULTS

Beyazit Square and its environs as shown in Figure 6, a 50 hectares = 500,000 m2 built area, has been selected for the comparative analysis due to the remarkable change that the square faced through the harsh urbanization over the last sixty years. Building footprints vector data (.tiff
images 1024x1024 pixels each) belonging to two different time periods, 1946 and 2013, have been used as raw data for information retrieval. Both data sets have been analysed through 10 different grid scales as shown in Figure 7. Multi-scalar analyses, the graphs in below Figure 8, revealed that the change with the cumulative entropic state, changing degree of wholeness of the square, as seen in the below Tables 1 and 2, has deteriorated, almost halved, from 0.32bit to 0.63bit entropy level within last sixty years.
Proceedings of the 11th Space Syntax Symposium

MEASURING AND VISUALIZATION OF SPATIAL CHANGE USING INFORMATION ENTROPY
Beyazit Square case area in Istanbul

Figure 6 - 50 hectares (500,000 sqm) Beyazit Square and Environ in 1946 (Left) and in 2013 (Right). (1024 x 1024 pixels each tiff vector data)

Figure 7 - Grids For Varying Scale Levels Superimposed Upon 1946 (Upper) and 2013 (Lower) Vector Data and Unit-Specific G Realizations

Figure 8: Multi-Scalar Analysis and G-IQR (Red Curve) and H-IQR (Blue Curve) Results for 1946 (Left) and 2013 (Right) Data
As seen in Table 1 below, for 1946 data, total sum of the h-iqr values for the pixel levels that have been tested is 0.32bit.

<table>
<thead>
<tr>
<th>Grid Scale (Pixel Level)</th>
<th>PA (Pixel Area sqmm)</th>
<th>Total Cell</th>
<th>NA Cell (exempted)</th>
<th>%</th>
<th>MA (Map Area sqm)</th>
<th>G-IQR</th>
<th>G-Q1</th>
<th>G-Q3</th>
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<th>H-Q1</th>
<th>H-Q3</th>
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<td>4761</td>
<td>272</td>
<td>5.7</td>
<td>0.006</td>
<td>0.87</td>
<td>0.130</td>
<td>1.000</td>
<td>0.07</td>
<td>0.050</td>
<td>0.120</td>
</tr>
<tr>
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<td>0.845</td>
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<tr>
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<td>0.400</td>
<td>0.780</td>
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Table 1 - G-IQR and H-IQR Values and Their Quartiles Generated for 1946 Data

As seen in Table 2 below, for 2013 data, total sum of the h-iqr values for the scales that have been tested is 0.63bit.

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Table 2 - G-IQR and H-IQR Values and Their Quartiles Generated For 2013 Data
The change trend with the quartiles for each grid level indicates that there is a remarkable decrease with the H-Q1 for the 2013 data compared to 1946 data. G-Q1 values for 2013 data change notably slower compared to 1946. This is mostly because of the massive destructions and thus the rising amount of empty areas in 2013 built configuration. Analyses through the same grid scales generated the graphs in Figure 8 above, show the behavioural change of entropy, h-iqr values, depending on the morpho- information levels framed by various size of grid units. From smaller to larger pixel levels, 2013 spatial configuration generated relatively higher G-IQR and H-IQR values compared to 1946 configuration. In brief, a wholeness-based spatial analysis for the selected areas reveals a higher tendency for uncertainty in micro scales but lower tendency in larger scales. This outcome verifies and points out to the fact that there is always a higher potential of spatial interaction among the references of micro space towards change. As the grid scale gets larger, the number of the grid units decreases and the number of exempted units proportionally increases due to larger unit size.

3.1 MODELLING THE ENTROPIC INTERACTION

Principally entropy indicates a level of tendency towards uncertainty or disorderness. Higher entropy means higher tendency towards uncertainty. From the spatial relatedness point view, a built area framed by a grid unit is spatially and geographically related with its adjacent units and intrinsically through each other’s entropic states. In other words, there is a constant interaction among the system parts. This can be visualized by an interaction modelling method.

In general, each grid system highlights the vertices of each unit area that they intersect with. Mutual effect interaction, described by Brannon (2008), is here interpreted as the displacement (deformation) of the four vertices of each unit due to the forces generated by the entropy values as explained in Figure 9-a above. For each of the vertices, displacement effect is the joint force of the entropic states of the connected units as in Figure 9-b. Following the displacement of the vertices, all of them are reconnected via straight lines as seen in above 9-c visualization. Then the straight lines are converted to the curves, 9-d/e, by using Centripetal Catmull-Rom curves algorithm that is widely used in computational data modelling as an explicit piecewise polynomial representation (Yuksel, Schaefer, & Keyser, 2011).

Entopic interaction way of data visualization generates a deformed grid that allows making evidence-based comparison of how morphologic occurrences relatively interact and possibly affect each other in various built environment scenarios. Such data modelling for the 2013 case, when compared to the 1946 deformed grid in Figure 10, implies the missing structural entities are leading to a growing degree of deformed unit areas in the west, south west and south units.
This explains that the relative effect of entropic interaction is in a parallel trend of change in accordance with the changing state of spatial configuration. Colouring in interaction modelling exposes how the multiple effect entropic interaction deforms the grids in heat mapping way. The colour scale shows the most deformed units in red and its shades while least deformed ones in blue and its shades. Purple and white colours are used for non-deformed units. Non-deformation means that there is no entropic interaction either among the fully built units, shown in purple, or among the fully non-built units, shown in white, due to equal entropy values among the adjacent units.

4. CONCLUSIONS

Spatial evolution or change, with an increasing trend, has been studied through diverse map-comparison technics in which both traditional and advanced techniques have been incorporated for various purposes such as detecting temporal/spatial change, comparing different models or scenarios, or for calibrating/validating land use models (Visser & de Nijs, 2006). The novelty and originality that this method, morphologic measuring and visualization using Shannon’s entropy, introduces is that it measures built environment through the notion of spatial relatedness which morphologically and intuitively articulates a relative degree of wholeness. Such wholeness, in addition to being context dependent, is also about the level of investigation since the system continually redefines its entropy through the changing morphologic interplay among the adjacent grid units.
This study develops an evidence-based approach for measuring spatial wholeness, e.g. completeness, and implements it on Beyazit Square, one of the major squares that has been densely influenced by the effects of automobile-led urban planning trends in Istanbul (Dokmeci et al., 2011) in the last sixty years. The success of the traditional neighbourhoods in Istanbul lies in the continuity of their growth as a whole. It is possible to feel this wholeness not only at larger scales but in micro space and its details (Dokmeci et al., 1996), (Alexander et al., 1987). The results show that the degree of wholeness of the square significantly decreased within last sixty years. This finding is also being verified in previously reported studies, the spatial assessments (IMM, 2012), (Protection Board, 2013) that have been developed by the experts in Metropolitan Municipality of Istanbul and in Istanbul 4th Protection Board for Cultural Assets. Both reports point out the poor and fragmented spatial quality of the square noting the remarkable morphologic change that the square faced within the last sixty years. Entropic interaction way of spatial interaction modelling also deforms the grid in accordance with the morphologic change the square faced as in Figure 10 above.

Being alive, in biological terms, is a very binary matter. There are only two major degrees, dead or alive, and no other states of existence. In space, there are varying degrees of completeness or incompleteness and this study hypothesizes that it is a measurable concept beyond intuition (Alexander, 2002-2005). Karaali and Karagol (2013) define spatial incompleteness as evocative of liminal states, such as circumstances annoying the user, dissonant matches, uncertain situations, ambiguous formations and undefined regions. Adapted to spatial analysis, there are varying degrees of completeness or incompleteness in built environment and this study, using Shannon’s information entropy theory, demonstrates that wholeness or completeness as spatial quality is a measurable notion. In brief, the proposed method as evidence based topologic investigation, is a promising approach to shed light on analytical assessment of morphologic possibilities and change scenarios.

ACKNOWLEDGEMENT

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REFERENCES


MEASURING AND VISUALIZATION OF SPATIAL CHANGE USING INFORMATION ENTROPY

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#59

THE CONSTRUCTION OF THREE METROPOLISES

A geographic, productive and configurational process.

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ABSTRACT

The explosive urban growth in developing countries has often resulted in social and territorial disparities, with zones well-provided with urban services, equipment and amenities for affluent groups and vast areas lacking infrastructure and services populated by the poor. This paper proposes that a configurational analysis of the urban process of metropolitan cities could shed light on the spatial mechanisms behind urban inequality. Specifically, we attempted to analyse (i) the historical urban tendencies related to changing economies and (ii) geographical constrains that determinate the suitable land for urban development.

Three Chilean cities (Santiago, Valparaiso and Concepción) accommodate more than half of the national population. For each metropolitan area, a set of historical axial maps was drawn (1875, 1915, 1965 and 2015) that were analysed in relation to the geography and productive activities of the moment. With the global (HH) and local (r3) integrations, the main changes in the urban structures were identified, highlighting the migration of the centres and the characteristics of the most integrated/segregated areas.

The trends of urban growth in the three cities evidence a process that starts with a geographic positioning of the city, very much in line with its economic vocation and viability, enhanced by a spatial configuration that potentiates both the geography and the economic potentials of the region. Nevertheless, when economic, social and cultural conditions vary the city adapts, centralities change and develop and in some cases the deep structure of the city changes. The configurational analysis allowed us to understand three very different cases which we believe can be compared and shed light in the development of other cities.

KEYWORDS

Urban growth, metropolitan areas, historical growth.
1. INTRODUCTION

In many developing countries, the explosive urban growth has been accompanied by high socio spatial inequalities, with well-provided areas inhabited by the accommodated groups on the one hand, and highly deprived areas populated by the poor on the other. Latin America, the most urbanised area in the world (ONU-HABITAT, 2012), has been part of this tendency and most metropolis of the region exhibit high levels of segregation and inequality. Irregular settlements, neighbourhoods impoverished by economic cycles or indirectly produced by public action, coexist with well-located wealthy areas, with exclusive services and high quality facilities (Clichevsky, 2000).

In the case of Chile, with over 87% of urban population (INE, 2010), the national population is centralised in its three main cities: 38% lives in the capital Santiago, and 20% in Concepcion and Valparaiso (Hidalgo & Arenas, 2009). Although these three cities have slowed their population growth in the last decades (2.0% Santiago, 2.5% Concepción and 1.2% Valparaiso between 1982-2002, according to Hidalgo & Arenas, 2009), they have consumed vast areas of surrounding territory: between 2009 and 2015 Santiago consumed 558 hectares in average per year, Concepcion and Valparaiso occupied 135 and 83 per year respectively (Valencia, 2016). Moreover, this explosive urban growth lead into a systematic socio spatial segregation process distancing the more affluent groups from the most deprived.

The national literature points out that segregation in Chilean cities has been indirectly promoted by public policies. Through aggressive governmental social housing programmes, massive production of housing was significantly increased and effectively decreased the number of irregular settlements, but displaced deprived groups towards a distant and poor periphery (Ducci, 1997; Sabatini, 2000; Rodríguez & Sugranyes, 2004). In parallel, the construction of highways and the liberalisation of the urban land markets triggered an intense suburbanisation of the countryside by higher-income groups (de Mattos, 1999; de Mattos, 2002; Hidalgo & Zunino, 2011). However, and despite both processes, this paper argues that the current social and spatial fragmentation in Chilean cities is deeper and has roots on (i) complex geographies which determinate the availability of land and (ii) changing economies that can trigger violent transformation on the urban dynamics.

2. DATASETS AND METHODS

A syntactic analysis of the three main Chilean cities –Santiago, Concepcion and Valparaiso– through their different stages of development was carried out in order to better understand the urban growth and construction of metropolitan areas. The main tool used was the axial maps, representing all public space and streets with the minimum number of straight lines that cover the whole system (Hillier et al., 1984). The axial maps of each stage allowed us to recognize the spatial configurations built by the relationship of each part with all the other parts of the system (Hillier et al., 1998; 2000). This approach highlights topological relationships; in other words, it recognises that the characteristics of a specific part are intimately defined by the correlations with the other parts of the system in which it lies (Hillier, 1996).

A group of historical axial maps was elaborated for each city highlighting four periods: (i) the first period (between 1870 and 1880) was marked by urban operations inspired in the Paris of Haussmann. (ii) The second moment (1910-1920) corresponds to the Centenary of the Republic, characterised by several urban interventions intended to sanitise and embellish the rising metropolises. (iii) Industrialisation process and the arrival of modern urbanism (1960-1970) are reflected in the third period. (iv) The fourth and last period (2005-2015) captures the effects of the neoliberal model established in Chile since the 80's until today. The maps were reconstructed using historical maps form the accorded periods. In the case of Valparaiso, the available maps of the 19th century did not cover the entire territory currently occupied by the metropolis, hiding key connections between the settlements of the time. The connections were inferred from written evidence but they are less precise than in Santiago and Concepcion.
After the construction of the axial maps of each metropolis, and with the use of Depthmap software, global (HH) and local (r3) integrations were calculated. The resulting maps were juxtaposed with the geography of the cities, recognising the geographical barriers that are relevant in Santiago (mountains), Valparaiso (hills) and Concepcion (rivers and wetlands). Furthermore, the main economic aspects of the city were captured in existing bibliography and later contrasted with the changes in the global and local integrations. Lastly, the maps of global integration along with the geography are fully represented in the figures of the paper. Local integrations are partially shown in minor fragments according to their relevance in the analysis.

3. THE THREE CITIES

Santiago de Chile is the capital of Chile and has almost 7 million people in a territory of 750 km2. Concepcion and Valparaiso have almost one million each in areas of 130 and 110 km2 respectively. Founded during the 16th century, Santiago is the oldest city of the trio, located between the Andes coastal range and the Pacific Ocean, in a valley crossed by three rivers: Maipo, Mapocho and Zanjón de la Aguada. Its central location in the country, crossed in the north-south direction by the Panamerican Highway and tensed east-west by its position between mountains and ocean, it has developed in a radial structure (figure 1).

Concepcion was part of the southern frontier of the country until the end of the 19th century, when the last territory unconquered by the Spanish Crown, the Araucania, was annexed to the recently formed nation of Chile. The current metropolis is in the estuary of the river Biobio, in a rich ecological area that includes wetlands and forests. The city exhibits two clear axes of urban development; one of them runs in the plains between hills and the river, while the other follows the coast. This area is home of four active ports (figure 1).

Valparaiso does not have a clear date of foundation, it emerges spontaneously in a small bay during the 16th and 17th centuries, and was the main part of the country until recently. It later conurbarated with Viña del Mar, the second city of the country, and in 1980 it became the legislative capital of Chile. Like Concepción, Valparaiso has two axes of growth delimited by the coastal line and the inner valleys. The coastal axis occupies littoral plains and the surrounding hills, creating natural amphitheatres. The second axis penetrates inland, following valleys created by smalls rivers and ravines (figure 1).

All three cities have known natural and man-made disasters -battles, earthquakes, great fires- and have been reconstructed more than once.

![Figure 1 - Santiago, Concepción y Valparaíso. Source: personal elaboration.](image-url)
3.1. SANTIAGO

The spatial analysis of Santiago in figure 2a shows the urban grid of the city towards the end of the 19th century. The city displays a pattern dominated by east-west roads contained by natural margins (the already mentioned rivers Mapocho, Zanjón de la Aguada as well as the Santa Lucía hill), transport infrastructures (train tracks on the east and southwest) and big boulevards inspired by the urban interventions in Paris at the time. Within those margins, the extension of the historical roads towards the west created a homogenous, regular, mainly orthogonal grid in which the richer population lived (DOMS, 2000). To the south, the regularity of the urban growth is interrupted by big plots owned by the Catholic Church. Outside this planned city, irregular settlements start to crystallise a less structured grid linked to the roads which communicate the city with the rest of the country and its countryside.

Due to the natural extension from the centre to the west, the highest values for global integration are in the roads which follow east-west directions. The integration of the historic centre and the aristocratic residential neighbourhoods are the highest in the city. The irregular growth also assigned high integrations to those roads that communicate the city with its surrounding territory. Along with the high east-west integrations, those external roads configure a cross-shaped pattern which will be intensified in the following decades with the exploitation of the –before unproductive– south periphery.

With the opening of artificial canals, the southern periphery was transformed into productive farmland, triggering a rapid process of fragmentation of the property along the Camino del Sur (South Road, current Gran Avenida, and part of the Panamerican Highway). This old north-south road, which connected Santiago with the small town of San Bernardo, was regularly divided in lots of one kilometre delimited by new east-west streets. The crossing between those new roads and the Camino del Sur configured the first sub-centres of the city and the first places with high local integrations outside the city centre (Forray et al., 2013). The new productivity of the south turned the pattern of high integrations from east-west to north-south and created a ‘tree-shaped’ configuration in which a highly-integrated road (trunk) collect transversal streets (branches).

However, the high integration of the south did not coincide with the movement of the more affluent groups. On the contrary, under a local interpretation of the Garden City, high-income groups sought refuge in the new eastern periphery, with low integrations and enclosed by mountains and rivers (Palmer, 1994). Those new suburbs, with curvy roads and big houses started a new process; the richest groups of the society would seek proximity with the services of the main centre, but distance from the rest of the city by enclosing themselves in the lower, but rough, parts of the Andes range (figure 2b)
This agricultural development was soon replaced by a strong industrial development and was attracting massive migration flows from the countryside. The new flows and the modern urbanism influence reinforced the growth north-south axis (figure 2c). Additional radial roads, supported by sound urban norms, are widened to receive motorised traffic and then urbanised with industries in their borders in the tree-shaped pattern described before (Parrochia, 1980; 1994). The simultaneous growth over several arteries configure the star shape of the current city; long avenues with high integrations guide the urbanisation process, while settlements with lower integrations fill the gaps between them. The north-south integration is reinforced by the industrial avenues, while the lowest integrations are now in new and differentiated models of urbanisation in the periphery.

At the same time, while wealthy settlements continue to move closer to geographical enclaves in the east, under a model based on the use of cars, in the other directions (south, west and eventually north) emerges a new deprived periphery, also with low integration. Produced by informal settlements and social housing policies, this new low income periphery sometimes following the appropriation ideals of John Turner (1976) or the sanitation governmental schemes (Figueroa, 2011; Greene et al., 2014; Figueroa & Forry, 2015) generated complex grids as infill to the integrated radial roads coming from the centre to the periphery.

In the last period (figure 2d) the metropolis experiments the ‘tertiarization’ of its productive basis with two growth processes: the extension of the periphery and the densification and expansion of the existing downtown. The neo-liberal policies support a real-estate development that follows the pre-existing roads, now transformed into highways, thus reinforcing the tree-shaped scheme. New suburban gated communities with low integrations also ‘jump’
over natural barriers (rivers and hills) and find unexplored natural enclaves (de Mattos, 2001).
Public policies push further social housing developments, intensifying the urban segregation
of the metropolis (Ducci, 1997). At the same time, the historic centre is densified and extends
towards the wealthy area in the east (Fuentes & Sierralta, 2004). This new expanded downtown
consolidates as the most affluent of the city (Tokman, 2006), with high local integration towards
its rich neighbourhoods, but with low global integration connections with the rest of the city
(Greene & Soler, 2004). A few minor centralities emerge in small towns or in big street crossings
(shopping) where integration is brought in through the presence of highways.

3.2. CONCEPCIÓN

Figure 3a displays the global and local integrations of the city of Concepcion at the end of the
19th century. The future conurbation has two independent systems separated by the river
Biobio: in the south, a productive system consisting of Lota’s coal mining and Coronel’s port
capacity (Vivallos & Brito, 2010); in the north, the main city and administrative centre of the
south, Concepción, sharing features with Santiago. Concepción, after being destroyed by an
earthquake during the 18th century was re-founded with an orthogonal grid exhibiting high
integration values. In following years (figure 3b), the southern settlements grow into their own
periphery maintaining their spatial configuration; while in the north secondary settlements
emerge around Concepcion adding complexity to this sector. The new settlements are irregular,
with low global integration, occupying geographical plains left by the river Biobio, its wetlands,
the coast and the hills. Among the hills meander the roads that link the urban area.

Figure 3 - Axial maps of Concepción (warm colours, high integrations, cold colours, low
integrations).
With modernity and the construction of heavy infrastructure the configuration of the conurbation is modified (figure 3c). Two bridges over the river link both northern and southern systems, creating a highly-integrated corridor between them. This corridor prompts the emergence of new settlements in the –until that time– inhabited south riverbank. In the north, Talcahuano, driven by the port and the metal industry, grows in fragments over hills, ravines and littoral planes, avoiding the wetlands and the land not suitable for construction. The new urban ‘patches’ have low integration values and established a pattern that will be repeated in the other settlements of the conurbation (Pérez & Salinas, 2009; Aliste, 2012). Each settlement will grow independently, centred on its own activities, adjusting its growth to the available land (Baeriswyl, 2009). Long roads communicate the system with integration values, which decreases as distance from the main centre increases. Nevertheless, all the roads go through the main centre (Concepcion), increasing systemically its integration. This is being reinforced with the construction of a third bridge and the highways linking the north and the southern systems.

The independent pattern growth exhibited by the parts of the system will probably be intensified in the following decades with the accelerated suburbanisation of the settlements. As figure 3d displays, each settlement keeps its own centrality (high local integrations), and grow with ‘tentacles’ or ‘islands’ on the suitable land (Rojas et al., 2009; Zunino & Hidalgo, 2009; Aliste, 2012). The values of global integration depend on their relation to the main core (Concepcion) and the sinuosity of the roads. The high integration of Concepcion is strengthened with new highways with big infrastructure (airports), shopping malls and new industries locating in their intersections.

3.3. VALPARAISO

In contrast with the two previous metropolises, Valparaiso was originally unplanned and does not have an ordered grid. It emerged spontaneously in the 16th century around a bay surrounded by hills (figure 4a). The analysis of this city at the end of the 19th century shows a grid with high integration in the low and flat areas of the bay, around the port. The hills show an irregular grid, with low integration values, that follow the topography of the place. The city is at the same time the most important port of the country, a key point in the global navigation (specially before the Panama Canal was built) and a popular beach for the affluent families of Santiago. At the north of Valparaiso, the town of Viña del Mar founded in the 19th century grows in the littoral areas created by the river Marga-Marga, starting point of the inner valleys of the area. The grid of Viña del Mar is regular, have almost only industries, and, contrary to Valparaiso, does not reach the coast. The link between the pair is through trains and a complex road that goes among the hills located in between (Muga & Rivas, 2009).

Figure 4b displays the situation of the city on the beginning of the next century, during Valparaiso’s economic boom based on its mining activities and international trade. The integration pattern of the system changes with the opening of the coastal and inner roads to the north and west respectively. Although Valparaiso keeps the highest global integration of the area, the global integration values increase in Viña del Mar, now the beginning of the inner road (Camino Troncal) and the geometric centre of the coastal road (Booth, 2014).

The grid of Valparaiso is reconstructed, after the earthquake and a later fire of 1907, with new avenues which increase the numbers for global integration. At that time, the affluent families, as they did in Santiago, start moving to the garden city of Viña del Mar, which is transformed from the former industrial area into a popular beach and suburb of Valparaiso (Cáceres & Sabatini, 2003). Inland, two new towns emerge around the Camino Troncal, Quilpué and Villa Alemana, growing linearly closely linked and integrated to the main road followed by a fragmented urbanisation of rough lands in the hills (low integration).

Valparaiso’s boom ends in 1930 with the decay of mining activities and the opening of the Canal of Panama, and starts a process of obsolescence and impoverishment. Informal settlements populate the hills with a tortuous and discontinuous urban grid. On the contrary, Viña del Mar becomes a resort for the richer groups of society. The city reaches to the coast with an ordered
and regular grid, luxurious chalets and second residences for the inhabitants of Santiago. The integration of Viña del Mar increases and the city becomes the administrative, commercial and business centre of the region (figure 4c).

Figure 4 - Axial maps of Valparaiso (warm colours, high integrations, cold colours, low integrations).

Finally, figure 4d displays the structure of the current metropolis, the integrated centre has been moved from the historical area (Valparaiso) to the new centre (Viña del Mar). Global integration exhibits its greatest values in Viña del Mar, Valparaiso has lower values. New highways increase the integration of the inner valley, accelerating their linear growth and triggering the urbanisation of the ravines that originally separated the valley from Viña del Mar (Muga & Rivas, 2009). The north repeats the scheme with linear urbanisations and inland development between the hills. Suburbanisation appears in two models; detached from the main area and connected with highways with the rest of the metropolis, and continues in the borders of Viña del Mar and the inner valley. Moreover, all the settlements (including the rich Viña de Mar) grow
irregularly over the hills, replicating the issues already displayed by Valparaiso; low integrations and connectivity which prevent the access to the services located in the lower parts (Vásquez & Ledesma, 2013).

4. CONCLUSIONS

The syntactic analysis of the three main Chilean metropolises displays three different processes of urban growth. In the case of Santiago, the growth follows a pre-existing national road, with high integration, in a tree-shaped scheme: radial trunk roads and secondary branches that stem into the neighbouring areas. In Concepcion, the growth is concentric around each one of the existing settlements that conform the conurbation. In Valparaiso, the model considers a change in centrality and longitudinal growth on the linking roads (figure 5). Nonetheless, the three models have particularities that are relevant to detail.

![Santiago: Urban growth over highly integrated roads](image)

**Figure 5** - Schemes of urban growth in Chilean metropolis. In red, movement of the centre.

Santiago proves that high global integration is not necessarily accompanied by services and facilities. The search of natural exclusive enclaves by wealthy groups dragged the financial district to places with high local integration but with low global integration. The high local integration makes the centre highly accessible to its affluent surroundings, but distant from the rest. Poor areas, on the other hand, are far from the main centre of Santiago.

Concepcion evidences simultaneous independent urban growths, which allowed the construction of local centralities with high local integrations. These are articulated through a system of roads that links them together with the original core. This implies that every trip made in the metropolis must go through Concepcion and thus it exhibits the highest global integrations in each one of the studied period. Authors, such as Rojas et al. (2009), have signalled that this pattern may jeopardise the development of minor centres that can be absorbed by Concepcion and reduced them to local administrative functions.

Lastly, Valparaiso is the only metropolis where the historic centre does not maintain the highest integration of its system. Viña del Mar, the neighbour city, displaced Valparaiso as the most integrated settlement of the metropolis by the middle of the 20th century. In this process, Valparaiso suffered a general process of impoverishment aggravated by a slow, but constant, migration of the services to the new centrality, Viña del Mar. The old core of Valparaiso went from ‘centre’ to ‘periphery’ while the geographical conditions of the place (hills) blocked the possible growth to inner land. The historic city, in contrast to Santiago and Concepcion, weakened with low global and local integrations in the metropolitan system.

There are signs of convergence in the growth of the three cities, though. The geographic complexity of the three sites, the presence of the Andes ranges in Santiago, the surrounding hills in Valparaiso and the river and wetlands in Concepcion, generates natural enclaves of poorly integrated values that facilitate the development of segregated areas, thus setting up the physical milieu that have allowed the development of the socioeconomic process of exclusion.
that characterises many Latin American cities. The construction of modern urban highways, that began in the nineties, accelerated the process of suburbanisation (either across the city, as is the case of Santiago, or linking the surroundings, as in Valparaiso and Concepcion), making it possible the construction of shopping malls and disperse centralities for the car.

Even more than the specific findings for each city, the main result of the exercise presented in this paper is to demonstrate that the configurational description of the three metropolises in a set of relevant time frames, coupled with the recognition of the geographical conditions, offers the possibility of synthetizing socio spatial patterns in the urban realm as well as the development of centralities. By understanding the productive development of the region at each time frame, and the geographical conditions as the possibilities and restrictions for its development, light can be shed on the mechanisms that generate the location and relocation of social groups, as well as the creation and growth of new centralities. The configurational relations expressed in the man-made urban grid, can be understood as an adaptive system relating its parts to respond to the needs and aspirations of the time, giving the form and nature to the metropolis itself.

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THE ROLE OF SPACE IN THE EVOLUTION OF LOCAL COMMERCIAL INTERACTION AND OBSOLESCENCE PROCESSES: The case of Cuauhtémoc neighbourhood, Mexico City

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ABSTRACT
Endogenous transformations of urban areas often have to do with spatial factors. This might be the case of spatial redistribution of economic activities. Economic units, and especially local commercial units, often evolve relatively fast in time developing interactions as to complement, compete, or even cancel each other. This, again, depends upon a number of factors some of which are spatial, such as locational advantage and proximity, framed by socio-economic like changes in consuming patterns, or a combination of both.

This paper presents the case of the Cuauhtémoc neighbourhood and its patterns of location and interaction of local commercial activities. The area gives an important example of the dynamics taking place in a leading financial centrality of the City, an area with country-wide relevance. Given its key location, next to the City Centre and in the middle of some of the most important thoroughfares, including Paseo de la Reforma, probably the most prominent location for national and transnational corporate buildings as well as for governmental offices, it has experienced several stages of evolution in terms of its land uses in the last decades.

Here we examine such changes through a detailed study of land uses at the micro level. We explore patterns of proximity between related uses, namely offices and their complementary uses, then spatial aspects are explored using space syntax. The information is then analysed statistically and compared. Findings suggest that there is a complex mix of factors, always conditioned or enabled by proximity, behind these changes. A cycle of functional obsolescence is observed where interventions in the most spatially important avenues, particularly in Paseo de la Reforma, act as “triggering events” for further transformations and interactions. Such events then generate the three kinds of interactions described above: cooperation, competition and conflict. This paper focuses on the first of this type of interactions, that of cooperation.

The study fits within a broader project aiming at establishing a new model to explain economic cycles within the Mexican land use market. It is implied that understanding of the dynamics that underlie these processes is key to adequate rehabilitation of traditional neighbourhoods such as the one studied.

KEYWORDS
Urban transformation, land use, economic units, location, proximity.
1. INTRODUCTION AND CONCEPTUAL FRAMEWORK

The conventional model in terms of urban reuse of space directly associates time and obsolescence as a simple linear function (Lichfield, 1989). It is a fact that owners’ income, in Mexico at least, often diminishes after the age of 60. This could be a cause for owners to prefer selling their property within any opportunity or signal from the market rather than covering maintenance expenses. However, the main thesis of this paper and the research that supports it is that this vision is only partially valid as space itself, through locational advantage and proximity, as well as the ‘struggle’ between defence of local traditions and acceptance of economic opportunities are also key factors in the dynamics of change of urban space.

Changes in an urban area are produced mainly, though not exclusively, by economic cycles. Each of these generate activities with specific spatial needs that start processes that can modify the territory. These processes are selective in space as they look for those locational circumstances that favour them to achieve the best performance of a particular activity (Camagni, 2005).

As it is well known, location requirements produce competition for specific areas or situations in a city. As a consequence, these particular places are reevaluated within the city as a whole, boosted by the agents and activities that lead the new cycle. In terms of the city’s transformation, this takes us back to the idea of urban life cycle (Lichfield, 1989) associated to urban form where economic transformations or cycles are expressed. The latter shown through investment cycles for urban transformation or adaptation of plots (Bon, 1998) and returns or favourable conditions that are produced by location of certain activities in specific urban areas that are being transformed.

As an area becomes more attractive and demanded for, it generates more competition for it, which in turn, pushes expectations for higher returns in that location. These detonate a new process where a new investment cycle is needed for the location advantages to become effective. New expectations become a kind of game between developers, investors, owners, residents and authorities, i.e. the market, where some owners will be interested in selling their property in order to capitalise or capture the advantages that the location of their plot offers to new or growing activities.

Since the process implies time of ‘assemblage’ of the real estate business that may vary depending on the specifics of each case and the conditions of the general economic environment, a condition of unsatisfied new expectations for the owner can appear where he becomes uninterested by the returns generated by the current use of his land. Therefore, the investment required for maintenance is seen as unnecessary and even opposed to his own good because it extends the life span of the existing use and so is at odds with the realisation of the new expectations or capitalisation. We call this process of estate decay caused by market investment, locational obsolescence.¹ It is suggested that, although the process is dependent on macroeconomic variables (interest rates, access to credit, economic growth, etc.), it starts when owners perceive the benefit derived from ownership of a property as unrealised capital. This is to say that the perception of benefit from it moves from the satisfaction of a need to obtaining of a specific, higher level of return. This can happen through transformation or physical adaptation of the property, or what we call functional obsolescence. When adaptation or transformation does not happen but this perception persists, maintenance often diminishes or stops, generating what we have called physical obsolescence.

This urban scale process is a result of a complex play that happens in specific plots and develops from the intensity of interests and values. The overall organisation of the city defines the advantageous locations for specific activities. The process then originates, on the one hand, from individual or group attitudes, which support or oppose an area’s transformation. Such

¹ For Lichfield, locational obsolescence refers to the progressive dysfunctionality between the original use of the building (activity) and changes in the neighbouring uses that promote changes in that given plot. It is a plot/building centred approach. For us, such pressure for adaptive changes, together with those associated with technological and lifestyle changes, fall in the category of functional obsolescence. We use locational obsolescence to pinpoint the pressures of change in a given neighbourhood or urban area imposed by the dynamics of the city as a whole. It is an area centred approach.
attitudes, we suggest, are directly related to the social position of these groups or individuals (Bourdieu, 1988) and will define their degree of sympathy or affinity for the anticipated changes. On the other hand, it comes from the functional relations of attraction or tension that are established between different uses in proximity that prompt complementary, competing or completely neutralising uses.

This paper presents preliminary findings on the role of space in influencing the definition of what we have called dominant uses and the influence of these in functionally related uses, together with other manifestations of change such as different types of obsolescence. These are described through one of our case studies: the Cuauhtemoc neighbourhood, focusing on office land use and its complementary uses.

2. THE CASE STUDY

It was during the Porfirian era (1876-1910) that a number of French-styled bourgeois neighbourhoods began to develop around the, also French-styled, boulevard (Paseo de la) Reforma. These neighbourhoods or colonias were called Roma, Juarez and Cuauhtémoc (Luiselli, 2003, p. 130-133). They were built with lower population density and good infrastructure by specialised companies and they expanded particularly between 1900 and 1910 (Garza, 2000, p. 120). The latter of these is introduced in this section as the case study for this paper.

The Cuauhtémoc neighbourhood takes its name from the Monument to Cuauhtémoc, last emperor of the Aztec Empire, that lies in one of its corners, in the crossing of Reforma and Insurgentes (Delegacion_Cuauhtemoc, 2011). These two avenues became the most important business corridors from the 50’s when saturation of the Centre caused it to overflow, particularly east and west (Lopez Rangel & Segre, 1986). Figure 1 confirms this predominance with service concentration running west and south of the Historical Centre and moving towards Reforma and Insurgentes respectively. Cuauhtémoc and its immediate southeast neighbour, colonia Juarez, represent the largest concentration of corporate employment in Mexico City.

![Figure 1 - Service concentration in the Metropolitan Area of Mexico City. There is clear concentration from the Historical Centre running southwest towards Reforma and south to Insurgentes. Cuauhtémoc neighbourhood outlined in red in the crossing of these two avenues. Source: Own elaboration based on DENUE 2014.](image)

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2 Paseo de la Reforma is still one of the most important avenues of the city. It was built on the orders of Maximilian of Habsburg (installed as ‘Emperor of Mexico’ by Napoleon III after a French invasion) in the fashion of Champs Elysees, connecting the city centre with the Palace of Chapultepec in a straight line. It runs north to southwest cutting diagonally the orthogonal layout left by the Spanish (Ortiz Chao, forthcoming, chapter 4)
With its key location, next to the Historical Centre and Chapultepec Park, Cuauhtémoc is at the midfield of market forces pressing for constant urban transformation. It faces Reforma on its widest side recognised as the main corridor of highly specialised services of Mexico City and where many governmental offices and some of the main national and transnational headquarters are located (Delegacion_Cuauhtemoc, 2011) (top photo in Figure 2). It is also in the middle of a number of other main roads: Insurgentes Avenue, another main thoroughfare with high service and employment concentration, and Circuito Interior, the first ring road of the city, a main road for high speed vehicular movement but a physical barrier in terms of pedestrian movement (bottom photo in Figure 2).

Figure 2 - Map of Cuauhtémoc neighbourhood showing main roads. Top photo shows Reforma Avenue. Bottom photo shows first ring road, Circuito Interior.

Source: Google Earth and Google Streetview.
The maps in Figure 3 show plot accessibility within the first ring of Mexico City. Again, Cuauhtémoc’s situation near the Historical Centre and among a number of main thoroughfares seems to give it its most important advantage spatially in spite of being located in the edge of the first ring road, Circuito Interior, a barrier for transversal movement.

![Maps showing plot accessibility](image)

**Figure 3.** Plot accessibility maps of first ring road of Mexico City showing axial choice (through-movement) RN and axial integration (to-movement) R3. Cuauhtémoc neighbourhood is shown in dotted lines.

**Source:** Ortiz Chao, 2008.

### 3. METHODOLOGY

A detailed survey was carried out in the study area, the Cuauhtémoc neighbourhood. The following characteristics were recorded:

a) Land use that according to the usual categorisation considers: residential, retail, services, facilities and industry.

b) Specific activities, that is, the specific function or service happening in each property and its scale of influence (explained below). For example, local retail for this case study included small grocers’, stationers’, chemists’, paint shops, costume shops, gift shops, movie rental shop, butcher’s, poulterer, grocery store.

c) Building levels, starting from ground level and on, in order to determine the distribution of building intensity in space.

d) Level of physical obsolescence, referring to the degree of decay resulting from the combination of exposure to natural elements and upkeep of the building, categorised according to the material conditions of each property as: no deterioration (1), paint detachment (2), loss of façade materials (3), structural damage (4), and in ruins (5).

3 This is a variation of the traditional space syntax model where plots become nodes attached to street nodes before calculating measures of accessibility (Ortiz Chao, 2008; Figueiredo & Ortiz Chao, 2015). It is used in this section to give a visually detailed picture of the study area within a broader context. However, axial lines are adopted for the spatial analysis section as the interest of the study is in the relation between streets and land uses (plots and buildings).

4 The term and the notion are taken from Lichfield (1989). The scale is an adapted and synthesised version of the methodology designed by the Escuela de Arquitectura Tecnica de la Universidad Politecnica de Catalunya (2006) used for risk evaluation of building conditions.
e) Level of functional obsolescence\(^5\), related to physical changes and adaptation to new uses within the original structure, and classified as: original use (1), partial adaptation, same use (2), new use (3), total remodelling (4), abandonment (5).

f) Market profile, which registered any properties that were on lease or sale.

All the information from the surveys was entered into a MapInfo database that allowed the creation of various thematic maps to start a territorial analysis of the Cuauhtémoc neighbourhood. These allowed us, first, to determine the dominant uses for the area as well as the subareas leading the process of change.

Taking Modis (2003) approach about market differentiation as a basis, we supposed that characteristics of agglomeration are given out of the nature of activities and the spatial-economical relation that links them together. A spatial categorisation was conducted to classify specific activities as regional or local according to their scale of influence. Local scale activities refer to those related to the reproduction of everyday family life; users usually have direct access to them, often by foot for a good number of residential units, hence, it generates scarce or null parking demand. Regional scale refers to higher-level activities that not only satisfy neighbourhood residents but attract people from other parts of the city, producing important movements and flows within the area. This categorisation also allowed us to establish functional relations of proximity between activities, whether these were of cooperation, competition or rejection. Here we focus on the relation of cooperation between the dominant use of offices and their complementary uses.

Then, we use axial map analysis to explore the syntactic characteristics behind the locational advantages of predominant uses.

4. DOMINANCE AND FUNCTIONAL RELATIONS

Figure 4 shows the land use map of the study area according to traditional categorisation (see section 3). It is clear that the predominant uses are residential (yellow) with 877 buildings (54%) and services (dark blue) with a total 335 buildings (20%). These are frequently located on blocks close to Reforma. When height is taken into account, the map shows an even higher intensity of service concentration next to Reforma with nearly every building in the top rank (15 to 46 levels) facing this avenue (figure 5). Mixed residential and service buildings can also be found across the area (light blue). They account for 12% with 189 properties. Other uses represent less than 5% of plots each.

As it can also be observed in figure 6, most of the service uses correspond to offices (blue). In fact, the latter account for more than 70% of properties with service activity in the neighbourhood. We can start to ascertain some sense of socio-economical predominance determined by location on Reforma that fades with distance from it. If we now place a boundary between Reforma and the parallel street of Rio Panuco that is just around 200m and a couple of blocks away, we notice that 67% of office buildings are located within this boundary.

On the other hand, a map illustrating functional obsolescence (figure 7) shows that Cuauhtémoc is in the midst of an important process of change even when it remains a generally conservative neighbourhood with: 74% of properties with their original use (residential and offices), 12% have experienced partial adaptation but kept the same use, 7% have changed use completely, only 1% have been remodelled, and 6% suffer abandonment. Change is concentrated on the area between Reforma and Rio Panuco and on the two main thoroughfares running on the perpendicular direction to these (NW-SE), Rio Tiber and Rio Rhin.

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\(^5\) Although the term is the same as Lichfield’s (1989) the actual content for the sake of our study goes beyond his definition in so far it defines a limit for the purpose of creating a scale to measure adaptive changes. (Flores Peña, forthcoming)
Physical obsolescence, on the other hand, shows that owners in Cuauhtémoc are willing to invest in their properties’ maintenance so the neighbourhood keeps an overall good state (figure 8) with: 70% of properties showing no damage, 22% with only paint detachment, 5% present loss of façade materials, 1% with structural damage, and only 2% in ruin conditions. It is important to note that all plots on Reforma in this last category are under construction referring an advanced stage in the process of change. The area concentrating the most physical damage is on the west between Rio Panuco, Rio Tiber and Circuito Interior. Even when this area is the newest one (the neighbourhood was populated from east to west side), it holds a lot of old buildings and the original uses remain for the most (figure 7).
THE ROLE OF SPACE IN THE EVOLUTION OF LOCAL COMMERCIAL INTERACTION AND OBsolescence PROCESSES: The case of Cuauhtémoc neighbourhood, Mexico City

Figure 6 - Map of Cuauhtémoc neighbourhood showing offices (blue) and hotels (yellow).

Source: Own elaboration based on site survey.

Figure 7 - Functional obsolescence map of Cuauhtémoc neighbourhood. Darker colour denotes higher obsolescence: original use, partial adaptation same use, new use, total remodelling, abandonment.

Source: Own elaboration based on site survey.
Cuauhtémoc is a very mixed neighbourhood in terms of functions. Spatial categorisation of activities included local and regional retail (10 and 20 categories respectively), local and regional services (32 and 23 categories) as well as local industry (3 categories). This then resulted in a complex matrix of functional relations between activities where every specific activity has interaction with at least another one being 3 the average number of interactions with other activities. This paper will focus on offices (service, regional) that as we have seen are the predominant use (along with residential) and their complementary uses. The relations were established as follows:

Each of these activities holds a relation of cooperation with office sites and was, therefore, visually and statistically analysed in a separate map. The most pervasive relations are shown in this paper. The first of these was presented in figure 6 showing office locations in the study area. We could establish 3 kinds of ‘leading’ office areas. First, there is the corporate headquarters along Reforma. Then, we find a high concentration on the blocks of the southwest end of Rio Panuco that include the Federal Electricity Company (CFE). Finally, there are the large office estates along Villalongin on the east end that house Telmex, the largest telephone company in Mexico. The rest of the office sites offer complementary services to leading offices and
headquarters. This explains their location inside rather than on the edges of the neighbourhood and next to the main offices. We had mentioned before that 67% of office buildings are located within 200m of Reforma, up to the street of Rio Panuco, pinpointing the locational advantages of this area.

Figure 6 also shows hotels, another characteristic use of the area although not as predominant (less than 5% of services), in yellow. The functional relation between these two activities is obvious: hotels take advantage of the conditions described above to accommodate for the needs of national and international corporate headquarters. 88% of them are located within the 200m-boundary of proximity we set between Reforma and Rio Panuco. Another interesting point to make is that Reforma houses 5-star hotels whereas hotels inside the neighbourhood area 4-star or lower category.

Figure 9 - Maps of Cuauhtémoc neighbourhood showing office (blue) - diner (yellow) uses, and office (blue) – stationers (red) uses.

Source: Own elaboration based on site survey.
A similar functional relation of complementarity or cooperation happens between offices and diners (figure 9 top) and offices and stationers (figure 9 bottom). The latter are dependent on employees of the former. Nevertheless, a lack of places to eat would certainly affect office workers of the area. Though there are only 9, 7 of them are within the zoom stripe, that is 78%. The situation with canteens is alike with 67% (4 out of 6) located between Reforma and Rio Panuco. Stationers are equally complementary with 6 out of 8 (75%) located within the proposed boundary.

![Figure 10 - Map of Cuauhtémoc neighbourhood showing offices (blue) and banks (red).](source: Own elaboration based on site survey.)

To certain extent, banks and restaurants follow a similar logic with 72% and 74% within the zoom boundary respectively. These services do complement offices. However, they take further advantage of the privileged (both spatially and socially/symbolically) location of the area as they also attract lots of ‘floating’ users, i.e. coming from outside the neighbourhood for business, leisure or other personal reasons such as visitors, tourists or passers-by. In particular, banks locate themselves in the main thoroughfares: Rio Lerma, Villalongin and, mainly, Paseo de la Reforma (figure 10).

Conversely, photocopying and courier services functional relation is with complementary rather than leading offices. This is supported by the fact that while 4 out of 6 (67%) photocopying outlets are situated within the Reforma-Panuco stripe, 3 of these serve the Public Registry of Property offices on the east corner of Cuauhtémoc leaving 75% of the remaining 67% located further inside the neighbourhood (figure 10). Courier services follow a related trend with only 1 out of 5 (20%) within the zoom boundary and 80% further inside.
5. LOCATIONAL ADVANTAGES

Figure 12 shows local integration $R_3$ of the area within the first ring road of the city, Circuito Interior (top) and global integration on an axial map of the study area (bottom). Table 1 shows the integration values for the most accessible streets within the study area on an axial analysis. Reforma has the highest integration values. It is a main thoroughfare of higher hierarchy than the rest of the roads in Cuauhtémoc. It runs northeast-southwest (NE-SW). Circuito Interior also shows high integration values, specially globally, but it is not considered in the table as it is a high-speed motorway which acts as a barrier (see Figure 2).

When compared with percentiles of plots with office use, the leading land use of the area, and its
The role of space in the evolution of local commercial interaction and obsolescence processes: The case of Cuauhtémoc neighbourhood, Mexico City

Figure 12 - Plot accessibility of Cuauhtémoc neighbourhood, shown in dotted lines, within first ring road of Mexico City, axial integration R3 (top). Axial map of study area showing global integration (bottom).

Source: Ortiz Chao, 2008.

<table>
<thead>
<tr>
<th>Street Name</th>
<th>Axial int R2</th>
<th>Axial int RN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reforma (NE-SW)</td>
<td>6.358</td>
<td>2.958</td>
</tr>
<tr>
<td>Rio Tiber (NW-SE)</td>
<td>5.672</td>
<td>3.002</td>
</tr>
<tr>
<td>Rio Lerma (NE-SW)</td>
<td>5.457</td>
<td>2.240</td>
</tr>
<tr>
<td>Rio Panuco (NE-SW)</td>
<td>5.396</td>
<td>2.571</td>
</tr>
<tr>
<td>Rio Rhin (NW-SE)</td>
<td>5.204</td>
<td>2.432</td>
</tr>
</tbody>
</table>

Table 1 - Axial integration of most integrated streets in study area.
complementary services, it seems that spatial characteristics do confer an important locational advantage as the most integrated streets, Reforma and Rio Tiber, have a predominant presence of offices over complementary services (Table 2). Rio Rhin has a slightly higher percentage of complementary services than offices (less than 2%). This could be due to the nature of the northeast part of the study area with much bigger blocks that house major, mostly public, facilities. In fact, given this peculiarity, Villalongin was excluded from Table 2. Northeast-southwest streets show higher presence of complementary over office services: Rio Panuco, Rio Lerma.

<table>
<thead>
<tr>
<th>Street Type</th>
<th>Axial Int.</th>
<th>% Office Plots</th>
<th>% Compl Plots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reforma (NE-SW)</td>
<td>6.358</td>
<td>37.7</td>
<td>33.9</td>
</tr>
<tr>
<td>Rio Tiber (NW-SE)</td>
<td>5.672</td>
<td>16.2</td>
<td>8.7</td>
</tr>
<tr>
<td>Rio Lerma (NE-SW)</td>
<td>5.457</td>
<td>14.5</td>
<td>25.4</td>
</tr>
<tr>
<td>Rio Panuco (NE-SW)</td>
<td>5.396</td>
<td>8.5</td>
<td>16.9</td>
</tr>
<tr>
<td>Rio Rhin (NW-SE)</td>
<td>5.204</td>
<td>20.3</td>
<td>22.2</td>
</tr>
</tbody>
</table>

Table 2 - Most integrated streets and percentile of offices and complementary services.

Percentiles of functional obsolescence (Table 3) in the most integrated streets denote that areas immerse in the most intense process of change are Rio Tiber (22.5% of plots), Rio Panuco (18.9%) and Rio Lerma (16.9%). Physical obsolescence, however, seems more significant if we look at it as the area defined between Rio Panuco, Rio Tiber and Circuito Interior. This area is the most homogeneous in geometry. It also concentrates the most residential uses and is the most conservative as it presents the highest degree of physical obsolescence, the most original uses and the oldest buildings (figures 4 and 7).

<table>
<thead>
<tr>
<th>Street Type</th>
<th>Axial Int.</th>
<th>% Functional Obsolescence</th>
<th>% Physical Obsolescence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reforma (NE-SW)</td>
<td>6.358</td>
<td>15.1</td>
<td>13.2</td>
</tr>
<tr>
<td>Rio Tiber (NW-SE)</td>
<td>5.672</td>
<td>22.5</td>
<td>6.2</td>
</tr>
<tr>
<td>Rio Lerma (NE-SW)</td>
<td>5.457</td>
<td>16.9</td>
<td>4.2</td>
</tr>
<tr>
<td>Rio Panuco (NE-SW)</td>
<td>5.396</td>
<td>18.9</td>
<td>10.4</td>
</tr>
<tr>
<td>Rio Rhin (NW-SE)</td>
<td>5.204</td>
<td>16.6</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Table 3 - Most integrated streets and percentile of plots with functional and physical obsolescence (categories 3 to 5).

Correlations between the predominant use, office, and space syntax integration were examined to understand the influence of configuration in the locational advantages pointed out. In order to capture this more accurately wherever office was the predominant use it was multiplied times the number of floors in the plot to create a measure of use intensity. This also seems to better reflect market forces and, therefore, the way economic cycles operate. Figure 13 shows the first of this correlations with local and global integration (left and right, respectively). Even though the data seems to follow a positive trend, the correlation coefficients are slightly low: 0.55 for local integration and 0.39 for global integration. The measure of choice was tried too, giving weaker correlations that are hence not included in this paper. Once the number of levels is taken into account, Reforma's prevalence concentrating office uses is evident with 395.
THE ROLE OF SPACE IN THE EVOLUTION OF LOCAL COMMERCIAL INTERACTION AND OBSOLESCENCE PROCESSES: The case of Cuauhtémoc neighbourhood, Mexico City

Since there is a strong geometric pattern in the area, the data was then divided according to the street orientation, particularly NE-SW or parallel to Reforma, and NW-SE or perpendicular to Reforma. Figures 13 and 14 show these correlations and their coefficients. While these somehow improve the correlations and thus the spatial characteristics help to better explain the locational advantages, the influence of Reforma does not seem to be captured by them. The NW-SE direction does not have a street that concentrates offices as much as Reforma on the NE-SW direction (Figure 14). The highest number of office use occurrences is Rio Tiber with 77.

The number of office uses from Reforma as starting point was also included (Figure 15). It is clear that frequency of offices, the predominant use in the study area, falls with distance (streets or blocks away, parallel) from this important thoroughfare. A similar graph was plotted for the NE-SW streets (Figure 16), from the southwest end, Leibnitz, to the northeast corner, Rio Tamesis. Apparently, the main peaks from the number of offices decays are Rio Tiber (77 office uses) and, in second place, Rio Rhin (72 office uses), both main roads crossing the neighbourhood, both enhanced with monuments in their crossings with Reforma.
6. DISCUSSION AND CONCLUSIONS.

It is clear that, even though time is obviously an important factor in the processes of obsolescence and urban transformation, space also plays a key role at different scales. First, it is space, through configuration, that determines the most advantageous locations in terms of economic activity and, therefore, the overall locational hierarchy in a city (Hillier, 1996; Hillier, Penn, Hanson, Grajewski, & Xu, 1993). This, of course, has social implications, both implicit and explicit. The former have to do with the socio-cultural information embedded in any urban configuration (Hillier & Hanson, 1984) whereas the latter refers to the identity and symbolic meaning associated to a place given its layers of historical background and evolution. This last aspect is being investigated at the moment.

Speaking of this case study, it is known that Reforma, besides being in a privileged and accessible location, is the most prestigious avenue in the City and, hence, the most profitable for the leading headquarters to locate themselves. Then there is the functional relations between activities that are also realised in and through space. In this example, there are other, smaller,
yet important, services, such as complementary offices, that locate themselves “on the back streets” of Reforma (they obviously cannot afford to be on or on the next street to this avenue). By being on these locations they can complement predominant offices while at the same time capture some regional costumers. Then, there are smaller service providers like photocopying and courier outlets that complement, for example, these “back offices” while still capturing some regional costumers, even when it is an even smaller proportion. All activities enjoy some locational advantages even when they do in different, proportional scales. At the same time, each one of these levels of economic activity is constantly competing for space and market with other providers in the same level.

While these activities attract and cooperate with each other, we notice that this influence also weakens or fades after a certain distance. We proposed a boundary from Reforma up to Rio Panuco, a couple of blocks and 200m away, where predominant uses, economic activity and building intensity seemed to concentrate which allowed us to observe functional relations in greater detail and determine levels and types of relations like the ones explained above. It could seem that centrifugal and centripetal forces’ present in the dynamics of agglomeration economies (Anas, Arnott, & Small, 1997) respond to spatial configuration, in the first case, and metric distance in the second.

The case study presented is work-in-progress done in one of four neighbourhoods of different socio-demographic characteristics so the ideas need to be developed further. However, it gives valuable answers that support the hypothesis of the importance of space in the economic differentiation and process of change in urban neighbourhoods of Mexico City. Next steps include examination of the social component that is being developed at the moment using surveys and demographic data and comparison across the four case studies. We hope to be able to develop generalising conclusions that lead us to important data that can help decision-makers understand the dynamics beneath urban transformation processes in the Central City of Mexico and other comparable metropolises.
REFERENCES


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STAR-MODELS AND URBAN DEVELOPMENT

An ethnographic and historical examination of the connection between urban form and spatial-cultures

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ABSTRACT

In this paper I use Space Syntax methods to compare the relationship between normalized syntactic descriptions of two Quebecois cities (Alma and Saint-Georges) and their respective spatial cultures. In order to do so, I combine into one typology two historical dialectics identified by Hillier and Hanson in their comparative work on cities (1984). The two dimensions of this typology stretch between global-to-local planning and local-to-global planning, and socio-cultural and micro-economic preferences. I then explain how Hillier et al.’s four-pointed star models place a city within this typology (2012). Finally, I use historical and ethnographic methods to see whether qualitative information on the social, economic, and cultural makeup of both places corroborates their syntactic descriptions. The NACH and NAIN analyses suggest that Alma was developed with relatively more global-to-local planning than Saint-Georges and relatively stronger emphasis placed on socio-cultural priorities over micro-economic ones than was Saint-Georges. I found that historical and ethnographic information on Alma and Saint-Georges corroborates this syntactic description.

KEYWORDS
Spatial Cultures, Normalised Angular Analyses, Urban Development, Quebec

1. INTRODUCTION

In this paper, I use Space Syntax methods to compare the relationship between normalized syntactic descriptions of two Quebecois cities (Alma and Saint-Georges), and their respective spatial cultures. In order to do so, I combine in one typology two historical dialectics identified by Hillier and Hanson in their comparative work on cities (1984). I then explain how Hillier et al.’s four-pointed star models can be used to place a city within this typology (2012). Finally, I use historical and ethnographic methods to see whether qualitative information on the social, economic, and cultural makeup of both places corroborates their syntactic descriptions. Alma and Saint-Georges, Quebec share a great deal of provincial and national history and have similar demographic and sociological features, however they have very different histories of urban development (Coté 1994; Vézina 1935). Alma was developed in Quebec’s central north – close to Lac-Saint-Jean – in order to house the employees of the hydroelectric, pulp and paper, and aluminum industries active in that area. Saint-Georges, on the other hand, was developed as a defensive outpost on the Chaudière River south of Québec City and near the border with the United States (Bolduc 1969). Because of their different histories of development, I hypothesized that these two settlements would be excellent places to study how spatial configurations contribute to spatial cultures.
2. THEORETICAL CONTEXT

Beginning in 1984, Hillier and Hanson argued that urban spaces were, in specific ways, reflections of underlying social processes (1984). Since then, comparative studies of the spatial properties of cities around the world have identified a dialectic between what can be simplified as generative micro-economic forces and conservative socio-cultural forces in urban development (Hillier and Neto 2002, 182). After comparing the Space Syntax of hundreds of urban grids, this research has postulated that an emphasis (whether in the minds of urban planners or in the minds of individual builders) on micro-economic processes tends to push urban geometry towards the conservation of a few long lines in what has been termed a city’s ‘structural foreground’ and the subsequent proliferation of many shorter lines in a city’s ‘structural background’ (Hillier 1998; Hillier and Neto 2002; Hillier and Vaughan 2007). Micro-economic activity has furthermore been seen to create urban configurations that maximize random contact between urbanites, while cultural preferences have been shown to create urban configurations that conserve patterns of co-presence between different social categories such as men and women, economic classes, and strangers and locals (Hillier 2009). Hillier and others have argued that this spatialized dialectic between commercial expedience and cultural preference produces similarities and differences which are observable in human settlements around the world. As Hillier puts it, 

On the one hand, a residential process driven by socio-cultural forces puts its imprint on local space by specifying its geometry and generates a distinctive pattern of local differences, because culture is spatially specific. On the other, a public space process driven by micro-economic activity generates a globalising pattern of space that tends to be everywhere similar because micro-economic activity is a spatial universal. (2002, 162)

The dialectic between expedience (cost-effectiveness and the maximization of contact) and cultural preference (stability and the ordered reproduction of social relations) has further been connected with observable differences between types of city that can be roughly placed on opposite ends of a spectrum from each other. On one end of this theoretical spectrum are cities that are created largely for the function of the reproduction of society in a particular cultural image – administrative capitals (Hillier 1984, 21). On the other end of the spectrum are cities that are created in the service of the exigencies of micro-production – business capitals. As Hillier writes, 

This kind of variation [patterned variation between cities globally] suggests a rudimentary typology of settlement forms based on the different balance between the micro-economic and socio-cultural forces. Where the economic process is dominant from the beginning, we find linear or cross-road settlements and these are usually found on major routes between larger towns, a linear town being ‘global structure only’. A deformed grid town is one in which both processes run in parallel. A regular orthogonal grid town is one in which the local cultural process is in the spatial image of the global economic process, as in mediaeval planted towns or early American towns, and where the whole grid is essentially a micro-economic rather than socio-cultural creation, as can reasonably be said both of mediaeval planted towns and early American grids. (2002, 175)

Because of the balance between micro-economic and socio-cultural forces in urban development, the degree to which an urban grid is deformed or linearly oriented can be used as a rough measure of the prevalence of one or another priority in a city’s history. In this paper I show how normalized measures of integration (NAIN) and choice (NACH) map onto historical differences in the development of Alma and Saint-Georges. I then discuss how different socio-cultural and economic forces are embedded in the material patrimony of both cities. Learning to represent and read this materialization of value is argued to be an important way to understand urban spatial cultures.

Before going further, it should be noted that the distinction between micro-economic processes and other types of economic activity is an important one. As the analysis in this paper will later show, and as Hillier and others have already surmised, economic development is very often wedded to the needs of administrative organs in modern states and in large corporations and industries (Hillier 1998). One should therefore not expect to see the same patterns
of development in any and all urban growth based on some form of production. Indeed, governments, companies, guilds and other such organizations often combine their notions of the ‘correct’ conservation of social relations with economic production (Bray 2005; Morisset 1998). This pattern is seen in planned cities the world over, and was, in fact, the case in Alma.

Given the differences between micro-economic and other types of economic activity, another dimension needs to be added to Hillier and Hanson’s original spectrum, namely the difference between cities that were planned as parts of a regional whole (global-to-local cities) and cities that were planned, or unplanned as the case may be, as centers for local activities of exchange, organization and etc. (local-to-global cities). The following table [Table 1] indicates the resulting taxonomy of settlements.

<table>
<thead>
<tr>
<th>Socio-cultural priorities</th>
<th>Local-to-global planning</th>
<th>Global-to-local planning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dense patterns in the city’s background network reflecting culturally specific preferences for the mixing or segregation of social categories.</td>
<td>Both foreground and background networks defined by the city’s administrative or cultural centers and the space surrounding them. Foreground network serves a representational function.</td>
</tr>
<tr>
<td></td>
<td>Foreground network deformed by the exigencies of the background network’s development.</td>
<td>Highly structured grid, tending in most cases towards orthogonal order. Little deformation of background or foreground networks.</td>
</tr>
<tr>
<td></td>
<td>Background network clustered around a well-integrated foreground network.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Both foreground and background networks maximize random contact.</td>
<td></td>
</tr>
<tr>
<td>Micro-economic priorities</td>
<td></td>
<td></td>
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<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As one can see from [Table 1], in global-to-local cities the foreground network tends to play a larger role in the organization of the city whereas in local-to-global cities the opposite occurs. In this typology, the differences in economic and socio-cultural cities stay the same. Economic cities tend to have a less deformed grid, which facilitates the efficient movement of goods and services, whereas socio-cultural cities have a more deformed grid that facilitates the conservation of social relations and the reproduction of cultural activities.

3. METHODS

Using the normalized variables of angular choice (NACH) and integration (NAIN) Hillier et al. introduced ‘star model’ representations of global urban form (2012). Star models graphically represent the maximum and mean values of both NACH and NAIN at a radius of ‘n’ in order to allow for a visual comparison of different urban systems along those dimensions. These normalized values produce numbers that are not relative to the size of their systems and therefore comparable across systems. In their paper, Hillier et al. argue that,

*mean and max NAIN show the ease of accessibility in the foreground (max) and background (mean) networks in the usual syntactic sense, while mean and max NACH index the degree of structure in the system: the mean NACH the degree to which the background network forms a continuous grid with direct connections, rather than being broken up into discontinuous sub-areas; while max NACH represents the degree to which the foreground grid structures the system by deformations and interruptions of the grid. (2012, 170)*

Converting road-centreline data to spatial segments in the DepthMapX software allows researchers to quickly compare large urban systems on the basis of their NACH and NAIN. After making this conversion, I analyzed Alma and Saint-Georges’ segment maps using a 1024 bin
Tulip angular analysis with a topological radius of ‘n’. In what remains of this section, I explain what maximum and mean NACH and NAIN values represent before presenting the actual results of the tulip analysis of Alma and Saint-Georges in the next section.

As Hillier et al. explain above, the maximum values of each system represent the foreground network because they index the street segments that have the highest angular choice or angular integration measures. Maximum NAIN values index the accessibility of the foreground network in an urban grid. Accessibility refers to the topological distance of each street segment from every other street segment in the system, in light of the angular differences between the connectivity of each segment. A high maximum NAIN value means that the foreground network – the system of main roads – of a city is easily reachable from all of parts of the city. In other words, high maximum NAIN values mean that the foreground network is accessible. A high mean NAIN value means that the background network of a city – its residential area – is easily reachable from all other parts of the city. Maximum NAIN indexes the foreground network of a city because the most highly integrated street segments are typically a city’s main streets. Mean NAIN values index the accessibility of residential areas because the vast majority of a city’s street segments are typically located in its background network. Because of this, background accessibility has a much greater impact on the system’s mean values than does foreground accessibility.

NACH values follow a similar logic. High maximum NACH values indicate high choice values in the ‘choicest’ segments through the city – that is its main streets and byways. Angular normalised choice is calculated “by counting the number of times each street segment falls on the shortest path between all pairs of segments within a selected distance (termed ‘radius’). The ‘shortest path’ refers to the path of least angular deviation (namely, the straightest route) through the system” (Hillier and Iida 2005, 475).

Because NACH values represent the straightness of urban routes, high maximum NACH values indicate that a city’s main streets are prioritized relative to its other streets. The city’s residential neighbourhoods are bent and broken in order to create straighter main streets. Conversely, high mean NACH values show that a city’s background network is relatively straight (its parts are not deformed by the foreground network or by its own design).

How can we relate four-pointed star models to the typology of micro-economic, socio-cultural, global-to-local, and local-to-global cities I presented in Table 1? We can do so by taking mean NAIN values as an index for the relative degree of socio-cultural deformation of a city’s background and foreground networks and by using structural scores (or NACH values) to see at what level each city is structured and therefore at what level decisions about urban geometry appear to have been made.

High maximum NAIN values indicate that a city’s foreground network is easily accessible from all other parts of the city. This suggests that a city’s main thoroughfares have played a prominent role in the development of the city. Hillier et al. found that maximum and mean NAIN values tend to co-vary (2012). Cities with high maximum NAIN values tended to have high mean values and vice versa. Taken together, high NAIN values suggest that a city has been developed with an emphasis on micro-economic priorities rather than on socio-cultural preferences. Ease of accessibility facilitates trade, movement, and random contact between different types of people. It also minimizes the ability of space to segregate urbanites into socio-cultural categories.

High maximum NACH values point to a great deal of linear structure in a city’s main arteries. Hillier et al. found that maximum and mean NACH do not always co-vary (2012). Sometimes a city could have very high maximum NACH values but relatively average mean NACH scores. What this suggests is that when a NACH maximum is high in a city but its mean NACH is relatively low, global-to-local structuration has created a top-down order with the help of the city’s main streets. Global planning creates, in other words, arteries around which residential neighbourhoods form. When maximum NACH scores are relatively low compared with mean NACH scores, the background network’s structure is clearly dominant over the foreground network’s structure.
Overall, Hillier et al. suggest that these features of a city’s configuration can be simplified by dividing the mean NACH into the maximum NACH and by comparing this with the relative strength of the mean NAIN (2012, 187). Once this is done, the resulting values place a city somewhere on the typology presented in [Table 1] and reproduced with a few modifications in [Table 2].

<table>
<thead>
<tr>
<th>Socio-cultural priorities (Low mean NAIN)</th>
<th>Micro-economic priorities (High mean NAIN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local-to-global planning (Low NACH score)</td>
<td></td>
</tr>
<tr>
<td>• Dense patterns in the city’s background network reflecting culturally specific preferences for the mixing or segregation of social categories.</td>
<td>• Background network clustered around a well-integrated foreground network.</td>
</tr>
<tr>
<td>• Foreground network deformed by the exigencies of the background network’s development.</td>
<td>• Both foreground and background networks maximize random contact.</td>
</tr>
<tr>
<td>• Background network clustered around a well-integrated foreground network.</td>
<td>• Highly structured grid, tending in most cases towards orthogonal order. Little deformation of background or foreground networks.</td>
</tr>
</tbody>
</table>

Besides analyzing Alma and Saint-Georges based on their syntactic features I also compared the histories of their urban development and engaged in six months of ethnographic research in each city. I lived in both places, made friends there, volunteered, attended public events, attended city-council meetings, and interviewed people from both cities who represented their respective communities as politicians, heads of large local administrative organs, or as business people.
4. RESULTS

Figure 1 - Segment Map of Alma showing NACH at radius ‘n’
Figure 2 - Segment map of Saint-Georges showing NACH at radius ‘n’
As one can see from [Table 3], Alma and Saint-Georges had nearly identical maximum NACH values, but Alma’s mean NACH value was lower than Saint-Georges’. This indicates that Saint-Georges’ background network – its residential area – is less deformed by sociocultural priorities or by its foreground network than Alma’s is.

Alma’s maximum NAIN value is slightly lower than Saint-Georges’ maximum NAIN value. This indicates that Alma’s foreground network is relatively harder to access than Saint-Georges’ foreground network. Alma’s mean NAIN value is likewise lower, as one would expect, than Saint-Georges’. This means that Alma’s background network is overall harder to access than Saint-Georges’. The NACH score for Alma and Saint-Georges compared with each city’s respective mean NAIN value is shown in [Table 4].

<table>
<thead>
<tr>
<th>NACH</th>
<th>NAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAXIMUM values</td>
<td></td>
</tr>
<tr>
<td>Alma: 1.56 &amp; SG: 1.57</td>
<td>Alma: 1.30 &amp; SG: 1.33</td>
</tr>
<tr>
<td>MEAN values</td>
<td></td>
</tr>
<tr>
<td>Alma: 0.87 &amp; SG: 1.00</td>
<td>Alma: 0.78 &amp; SG: 0.82</td>
</tr>
</tbody>
</table>

Table 3 - NACH and NAIN values comparison between Alma and Saint-Georges (SG)

<table>
<thead>
<tr>
<th></th>
<th>Alma</th>
<th>Saint-Georges</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAIN mean</td>
<td>0.78</td>
<td>0.82</td>
</tr>
<tr>
<td>NACH score</td>
<td>1.79</td>
<td>1.57</td>
</tr>
</tbody>
</table>

Table 4

Given the mean and maximum NACH and NAIN values for Alma and Saint-Georges it is possible to locate both cities on the typology shown in [Table 5].

<table>
<thead>
<tr>
<th></th>
<th>Local-to-global planning (Low NACH score)</th>
<th>Global-to-local planning (High NACH score)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Socio-cultural priorities (Low mean NAIN)</td>
<td>Alma</td>
<td></td>
</tr>
<tr>
<td>Micro-economic priorities (High mean NAIN)</td>
<td>Saint-Georges</td>
<td></td>
</tr>
</tbody>
</table>

Table 5
Because Alma has a lower maximum NAIN value, a much higher mean NAIN value, an equal maximum NACH value, and a much lower mean NACH value than Saint-Georges, we can say that Alma is expected to be a city planned more on a global-to-local level with socio-cultural priorities emphasized in its construction rather than micro-economic ones. In Saint-Georges we can say that since the city has a higher mean NAIN value than Alma and a lower NACH score, it is closer to being planned from a local-to-global level and with micro-economic rather than socio-cultural priorities.

Since it is possible to produce a numerical basis for the qualitative typology presented in [Table 1], is there a way to corroborate that a city was, in fact, largely developed by local-to-global rather than global-to-local planning, and with micro-economic rather than socio-cultural priorities? If it is theoretically possible to measure the position of a city in relation to two different syntactic dimensions, is it also possible to confirm by methods other than the syntactic what the syntax of a city suggests about its material patrimony?

One way to try and answer this question is to study the historical development of both cities and to engage in an ethnographic examination of how people live together in each. Presumably, cities that are based on more global-to-local order will have a clearer statement of ideological planning than cities based on the local and uncoordinated prerogatives of individual builders. The very existence of a municipal ‘master-plan’ is evidence, depending on the longevity and comprehensiveness of its mandate, of global-to-local planning. An absence of such a plan or clear directives for municipal development is evidence for more local-to-global planning.

5. HISTORICAL CONTEXT

Alma has a population of 26,016 people in its urban area. Historically, Alma is the result of the Quebec government’s amalgamation of four smaller municipalities in 1962 (Meynaud and Léveillée, 1972). Isle-Maligne, Naudville, Riverbend, and St. Joseph d’Alma were independently founded in 1924, 1943, 1925, and 1917 respectively (Tremblay 1967). Isle-Maligne and Riverbend were both built by companies to house their workers (Côté 1994). The Price Brothers Company built Riverbend in 1924, whereas the Aluminum Company of America (Alcoa) and the Duke-Price Company began construction of Isle-Maligne in 1924, starting with the ‘quartier de bosses’ (Côté 1968). Naudville was incorporated in 1943 because the towns of St. Joseph d’Alma and Riverbend refused to pay for sanitation, education, or other infrastructure for the new community, which had been built by property owners from St. Joseph d’Alma (ibid). Naudville was intended to be a dormitory community for the factories in Riverbend and Isle-Maligne. As such, the nascent village had little commerce or industry of its own and consequently found itself in a great deal of debt after trying to pay for its roads, sewers, and schools. Naudville’s debt load was the central motivation for the amalgamation in 1962 of the four towns comprising modern Alma (Meynaud and Léveillée, 1972).

Riverbend’s layout was based off a master plan influenced by the garden city movement in the United Kingdom (Côté 1994). Its curving streets centered on a communal park and community hall, and its Tudor and American Vernacular style homes were clearly organized by socio-economic status and ethnicity (ibid). The highest ranking managers of the Price Brother’s Company paper factory were located in the most structurally segregated streets of Riverbend on its northwest side, whereas the homes of the lower level managers and machine foremen were located on more integrated roads closer to the railway tracks around the town’s east and south sides (ibid). The managers living in Riverbend were of Anglophone (British, American or English Canadian) extraction while the labourers housed in Saint-Joseph d’Alma and Naudville were of French-Canadian and Francophone origin. This socio-cultural segregation was also materialized in the work camps of the Quebec Development Company for the hydroelectric damn project on Isle-Maligne and the subsequent town of Isle-Maligne (Côté 1968). In both places, workers were purposely segregated according to their ethnicity. Separate roads or subdivisions were also built for the company’s bosses and managers apart from the company’s manual labourers in order to further segregate the labour force based on economic class (ibid).
St. Joseph d’Alma, unlike the other three parts of Alma, was originally built around the Roman Catholic Church’s administrative facilities next to the Petite-Décharge River (Tremblay 1967). This village’s urban structure centered on the Church and the Seminary behind it, a deformed urban grid radiated out from the main road that ended at a right angle to the face of the Eglise St. Joseph. The grid of St. Joseph d’Alma was renovated in the 1960s after Alma amalgamated. St. Joseph d’Alma became, for all intents and purposes, the ‘downtown’ of the new city of Alma and was the primary center for local commerce even before the amalgamation (Lussier 1980).

In sum, Alma is a city that was mainly created to house the workers of large companies. Ethnic and class segregation was built into the city along with the preference for idyllic country living expressed in the geometry, landscape architecture, and domestic architecture of the garden city movement. St. Joseph d’Alma was the only part of the city built as a commercial hub for local farmers. Like most other such settlements in Quebec, it was centered on the administrative and religious facilities of the Roman Catholic Church. Though Alma was undoubtedly the product of industry, and therefore of productive processes, it was created from scratch to embody the socio-cultural preference for ethnic and class division. The parts of Alma, such as Naudville and St. Joseph d’Alma, which were not planned by corporations, were structured on a variation of the orthogonal grid. In Naudville’s case, the urban layout was in the shape of the simplest variation of an orthogonal grid, and in St. Joseph d’Alma’s case it was in the shape of a grid that was slightly deformed by the dominant presence of the Church and its seminary.

Saint-Georges is a city with 32,173 residents at the time of the last available census data. Its contemporary extent was created by the amalgamation of Saint-Georges Ouest, Saint-Georges Est, Aubert-Gallion, and Saint-Jean-de-la-Lande in 2002 (Lussier 2005). The municipality of Saint-Georges-Est was formed in 1907 but was not incorporated until 1948 (Bolduc 1982), the municipality of Aubert-Gallion was erected in 1856, the municipality of Saint-Jean-de-la-Lande in 1933, and the municipality of Saint-Georges-Ouest in 1947. All of these settlements grew out of the seigniorial land tenure system that was in place in French Canada from 1627 until it was abolished by British royal decree in 1854 (Lamonde 2013). Born from the French nobility’s experience distributing and organizing land in Normandy, the seigniorial system in Quebec centered around the distribution of seigneuries to prominent colonialists who were then expected to manage the division of their land into lots – usually oriented towards a river – as well as the settlement of these lots by censitaires (also known as habitents) and the development of a mill for grinding grain, a seigneurial house for collecting rents from the habitents, and potentially a courthouse or commune for the area’s residents (ibid).

Most of the early urban development of Saint-Georges was fundamentally determined by the seigniorial system (Bolduc 1969). The majority of Saint-Georges’ roads follow the plot lines (or rangs) of the agricultural strips that extend back from the Chaudière River. Towns in the Chaudière valley were gradually built up around a seigneurial mansion and its corresponding church, mill, and courthouse.

In sum, Saint-Georges’ early development was oriented by its river and by the social hierarchy built into the seigneurial division of land along with the cultural organization of space provided by the Catholic parishes (Ferron and Cliche 1974). There was no specific segregation based on ethnicity or language in Saint-Georges even though the fourth seigneur of Aubert-Gallion, one William Pozer, brought to Quebec nearly two hundred colonists from his native Germany who were originally protestant and German speaking (Garant 1946). Nor was there any particular segregation based on occupation (Ferron and Cliché 1974), although there is some evidence that wealthier habitents tended to live closer to the center of the settlement which gave them quicker access to the amenities provided by the seigneur (Lamonde 2013). More formalized systems of urban development were not introduced to Saint-Georges until 1951 when the first zoning laws were enacted and the roads in Saint-Georges were systematically changed from their original toponomy, which tended to recognize the seigneurial and clerical elite, to numbered streets and avenues, which were considered more modern (Bolduc 1982). Since the beginning of Saint-George’s development the municipality has been based, it seems, on expediency. No special values have been built into its efficiently elongated grid pattern.
6. ETHNOGRAPHIC CONTEXT

Speaking with people in Alma about their city I noticed five salient themes. First, everyone I spoke to underscored that Alma was a city dominated by ‘les grandes industries’. Second, people emphasized that Alma was a place with few class differences, a place where, as one resident explained, the upper classes were only slightly ‘above’ the lower (this resident was herself an architect and lived in Riverbend). Thirdly, the issue of community integration was often spoken about. My interlocutors told me that Alma was meant to be an inclusive community. This perception of Alma’s collective priorities seemed to be supported by the city’s municipal council, which made Alma’s motto, “Ville de l’hospitalité”. A great deal of the city’s public art, including a large sculpture of a blooming flower in front of its central library, was also dedicated to the theme of integration. Fourthly, the people I spoke to were worried about the future of their city. While I was there (August 2015 to February 2016) machine number nine in the paper factory closed, resulting in the layoff of forty-five people (Tremblay 2015). Three years previous to that, a protracted labour dispute between Rio Tinto Alcan and its employees cost the city millions of dollars in economic activity (Gauthier 2012). Overall, people seemed unsure about what large transnational interests would do with the factories that had supported Alma in the past. Finally, people in Alma were very interested in the natural environment surrounding their city. Many people hunted or fished (there was a large festival in autumn dedicated to celebrating ‘la chasse’), and many others skied, snowmobiled, hiked, ran or biked on the extensive provincial bike-network built into and around Alma. In the summer, Almatois could often be seen picking wild blue berries by the side of the road, and in the winter ice-fishing villages blossomed on the frozen river across from the home I rented. What had been bike paths in summer were made into snowmobile paths in winter, and a series of public parks scattered throughout the city were always busy with hikers, joggers, skiers or people snowshoeing.

People in Saint-Georges were also quite active, although hunting and snowmobiling seemed more popular there than were skiing or biking. When I spoke to Saint-Georgians about their city I noticed three salient themes. First, Saint-Georges was presented as a business friendly place. I was often told that people living in the ‘Beauce’ (the broader region surrounding Saint-Georges) like to own their own businesses and to be their own bosses. Indeed, this was a theme that was commonly observed in the city’s newspapers and institutions as well. There is a museum and a special school for entrepreneurship in Saint-Georges and the city’s self-made business acumen was widely praised and theorized in Quebec’s provincial newspapers as well as in scholarly materials about the area (Palard 2009). Second, people living in Saint-Georges did not seem, as far as I could tell, to invest their identity in the landscape as much as people in Alma did. People told me that if you were born in the Beauce you were always Beauceron(nes), but that seemed to refer mainly to an attitude rather than any specific attachment to the land. If this attitude could be distilled – as it was by one friend of mine – it might be said to be a fierce desire to be independent. Independence was the third salient theme I noted. A Beauceron friend explained to me that he did not want to be a ‘functionary’ in a government office. He told me that the point of life was to work, but more particularly, to work for oneself. In sum, working for the government or being otherwise supported by the state was seen to be a very undesirable outcome.

7. DISCUSSION

What does the ethnographic and historical record allow us to add to the syntactic descriptions of Alma and Saint-George? A comparison of the two city’s NACH and NAIN values suggests that Alma should be a settlement wherein socio-cultural priorities have been foregrounded more so than in Saint-Georges, and where global-to-local planning has been more predominant than in Saint-Georges. The historic record of both cities appears to support these syntactic conclusions. Global-to-local actors including the Quebec Development Company, the Price Brothers Company, and the Aluminum Company of America planned large parts of Alma. This was not the case in Saint-Georges. Whereas Alma was developed largely by neighbourhood section (or by whole town), Saint-Georges was developed largely by the gradual extension of streets. The historical record also suggests that socio-cultural priorities, namely the spatial deployment of a
hierarchy of classes, and the segregation of ethnicities, were present to a much greater degree in the planning and design of Alma and its constituent communities than they were in Saint-Georges.

Without having the space to go into my ethnographic work in great detail, the broad summary I provided of the salient themes I noted in my discussions with people living in both cities seems to support the syntactic description of Alma and Saint-Georges provided by NACH and NAIN measurements. People living in Alma felt that their city was much more connected to global forces – in the shape of the international industries that had founded their city. People in Alma seemed to be likewise more interested in questions of socio-cultural identity. One index of this interest in identity is the fact that people in Alma voted for the Parti-Québécois, a nationalist party, in every provincial election since the party’s development in the late 60s and early 70s. People in Alma also voted in favour of both referenda on whether Quebec should separate from Canada (the first in 1980 and the second in 1995). The Saint-Georgians I spoke with were, on the other hand, suspicious of global planning and preferred localized industry (another word for micro-economic activity perhaps). It was generally easier to speak English in Saint-Georges as well (more people knew English and it was seemed more ‘acceptable’ to do so), and concern over one’s socio-cultural identity seemed to be less pronounced than it had been in Alma. Voters in Saint-Georges have also never elected a candidate from the Parti-Québécois, preferring instead to elect federalist and pro-business Liberal candidates or, for a brief period, members of the Action Democratique du Québec, a right-leaning ‘populist’ party that defined itself as being autonomist as far as Quebec’s relation to Canada was concerned (ADQ website 2011; Farney and Rayside 2013). Saint-Georgians also voted against both referenda on whether Quebec should separate from Canada.

8. CONCLUSION

In this paper I compared the spatial cultures of Alma and Saint-Georges by using their NACH and NAIN scores to place them within a typology that stretched between global-to-local planning and local-to-global planning and between socio-cultural and micro-economic priorities. Based on their syntactic properties I found that Alma was expected to be a city planned closer to the global-to-local level and with relatively greater emphasis given to socio-cultural priorities. I then compared these syntactic findings with a brief historical and ethnographic examination of both places. I found that the historical record of urban development in Alma and Saint-Georges supports the syntactic description of both places. Many of Alma’s parts were planned by large corporations from the top down and were explicitly intended to embody a preferred arrangement of social classes and ethnicities. Saint-Georges, by contrast, was not settled through state or corporate intervention but largely developed through the local priorities of the area’s seigniors and residents. Ethnographic investigation further supported the syntactic description of both cities. I found that people in Alma were well aware of the global influence on the development of their town and I also found that questions of socio-cultural identity and integration were of continuing concern. In Saint-Georges, most residents emphasized local business and entrepreneurship along with the desire for political autonomy.
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CAN THE ORGANISATION OF COMMERCIAL SPACE IN CITIES ENCOURAGE CREATIVITY AND ‘SELF-GENERATING’ ECONOMIC GROWTH?
A return to Jane Jacob’s ideas

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ABSTRACT
This paper explores the implications of Jane Jacob’s ideas about the ‘self-generating economic culture of cities’ (Soja, 2000) for the way in which urban commercial spaces are organised and managed. Jacobs saw economic development as an emergent process, based on economic branching, and the development of ‘new work on the basis of old’. Drawing on three case studies from London (on railway arches, the Winkley Road Estate and Gillett Square in Dalston) this paper explores the key spatial factors which Jacobs identified as supporting bottom-up economic growth, such as the intermingling of old and new buildings of different types, sizes and conditions; the mixing of commercial and residential uses; and high population density. In her later works, Jacobs shifted away from her neighbourhood focus to explore how city economies work more globally, highlighting the multiple opportunities for collaboration offered through diverse city supply chains. At this point she did less to imagine how the physical structure of cities might play an enabling or constraining role. The paper concludes by suggesting that Space Syntax might have something to contribute here, through underlining the importance of local-global spatial linkages in cities.

KEYWORDS
Jane Jacobs; commercial space; cities; emergent growth; economic development; innovation; mixed-use; diversity; entrepreneurship

1. INTRODUCTION
In her book The Economy of Cities, Jacobs (1969) argued that new work emerges on the basis of the fragments of older work. She famously gives the example of the New York dress maker who began to experiment with bra-manufacture, and later developed this side-line into a successful business. Jacobs sees economic development as a ‘branching’ process which is based in part on the imagination and problem solving of workers, who develop new work after ‘tinkering, taking apart and reproducing’. At the same time, cities offer diverse possibilities for new products to
be brought to market, through the presence of complex supply chains. The bra manufacturer in New York needed a whole host of different inputs when setting up her new company including packing, advertising and distribution, that were all available to her in her local neighbourhood. Jacobs finds that new work is often built on the ‘fragments’ of older work, and that smaller companies with cultures of relative inefficiency are often the most fertile grounds for new innovation. As companies grow and become more efficient, they tend to eliminate waste, providing less opportunity for people to experiment with different products and develop new ways of doing things.

As cities become more diverse, Jacobs feels that this sets up a virtuous circle – ‘the greater the sheer numbers and varieties of divisions of labor already achieved in an economy, the greater the economy’s inherent capacity for adding still more kinds of goods and services’ (1969 p.59). This idea has been substantiated in recent studies: Youn et al (2016) looked at data on NAICS codes for 366 metropolitan statistical areas in the United States and identified super-linear scaling of economic diversity over time, suggesting that cities keep adding new work to old, and support economic branching even when very large. This is despite the fact that both the total number of establishments and total number of employees only scales linearly. After analyzing micro-data on changes to occupational titles in US cities, Lin (2009) also found that workers are more likely to be observed in new types of work in locations that are initially dense in both college graduates and industry variety.

Jacobs’ focus on the role of concrete problem-solving in spurring innovation has also been developed elsewhere in the economics literature - for example, Jensen et al (2007) argue that much innovation comes from ‘doing, using and interacting’ (DUI) as opposed to formal scientific research and development practices. Cooke (2016) argues that such innovation is like ‘dark matter’ in that it is largely invisible to research, but is very much responsible for what he calls ‘generative growth’. Elsewhere Toner (2011) has argued, like Jacobs, that middle-level workers are particularly important contributors of such incremental innovation - as Jacobs writes – ‘when humble people, doing lowly work are not also solving problems, nobody is apt to solve humble problems’ (1969). In fact, Jacobs was a very early proponent of the ‘creative city’ in its broadest sense, suggesting that cities should provide all their residents with opportunities for creativity. This is a very different way of thinking about the creative city than theories based on a more privileged ‘creative class’ (Florida, 2002).

Like Massey (1984), Jacobs saw economic activities as being intrinsically ‘spatial’ – not only in terms of being based in places such as cities, but also in terms of developing within particular physical buildings and streets. In Death and Life of Great American Cities (1961), for example, she went into detail about the physical factors necessary for lively city neighbourhoods, including the mixing of residences and working places; small and short blocks; the intimate intermingling of buildings of different ages, types, sizes and conditions of upkeep, and high concentrations of people. While these factors reflect Jacobs interest in developing successful residential areas, they also point towards an organisation of space that can promote economic growth and entrepreneurship. Her focus on the intermingling of different building types, in particular, highlights the importance of cheap commercial spaces that support creativity and experimentation, and that are flexible enough to support expansion and the branching of firms into new spaces and locations as they grow.

Jacobs ideas about the spatial dimensions of bottom-up economic development have been developed by a number of architectural theorists. For example, Davis (2013) asserts the importance of developing hierarchies of different spaces in cities as a key tool in encouraging economic diversity, drawing on research in areas of London such as Whitechapel and Dalston. Rantisi and Leslie (2010) likewise identify how small-scale makers in the creative sector need spaces that are unfinished and expandable. The discipline of Space Syntax has also explored how the spatial morphology of urban neighbourhoods might influence the mixing of commercial and residential uses. This discipline has shown, for example, that the configuration of streets in cities produces underlying patterns of pedestrian and vehicular movement that then have knock-on effects on how the locations of commercial activities develop. Space syntax has also explored how the organisation of space might encourage encounters between people and
hence opportunities for communication and collaboration (Hillier and Penn, 1991).

In her later works, such as The Economy of Cities, Jacobs shifted away from her neighbourhood focus to explore how city economies work as a whole, highlighting the diverse opportunities for collaboration offered through global city supply chains. However, she did not explore the physical properties of such creative city economies beyond restating the key principles for lively neighbourhoods that she set out in 1969. This means that while we have an increasing understanding of what a creative neighbourhood looks like, we have less understanding of how creative and ‘generative’ city economies might work spatially at a larger scale. One interesting current line of enquiry is the role of local-citywide spatial linkages. Read (2015), for example, identifies that cities are multiscale, with their residents ideally having access to both their local neighbourhood, and broader city level networks at every point in the urban system. He documents how ‘fine-grained neighbourhood to city economic relations’ have been key to the flourishing of city economies at certain points of history, where somewhat haphazard informal neighbourhoods being effectively linked into broader city markets through ‘switch points’ (Read and Budiarto, 2003) or ‘stitches’ (Turner, 2009). He suggests that such switch points might boost economic networking in the city as a whole. Hillier similarly identifies how the ‘dual structure’ of foreground and background networks in cities is often closely linked, with a ‘two step logic’ operating in the City of London, for example, whereby it never takes more than two changes of direction to find yourself on one of the main roads running through the system (Space Syntax Ltd, 2008). Such close interconections may again support synergies between local commercial spaces and more global economic networks in cities.

This article seeks to explore these factors in more detail through looking at three case studies, all drawn from London – that of London’s railway arches, the Winkley Estate in Bethnal Green and Gillett Square in Dalston. Each of these case studies demonstrates how the spatial principles identified by Jacobs and others as being important to economic development can be realised in practice.

The three case studies were studied through a variety of techniques. The railway arches research drew on the use of historical sources, direct observation of present spaces, and space syntax analysis of maps situating the arches in the larger urban fabric. The Winkley Estate has been studied through the development of detailed architectural plans, the use of historic street directories, observations of current uses, and the development of j-graphs to understand detailed building relationships. And Gillett Square has been analyzed through direct observation, interviews with the former director of the organisation that developed the square, and the use of historic and contemporary maps that describe and situate it.

2. CASE STUDIES

Railway arches: a lifeline for manufacturing in London?

The first case study involves railway arches—the thousands of individual spaces that were formed by the construction of the railway viaducts in the nineteenth century. These structures, all over London but mostly south of the Thames, were built to allow the tracks of the main line railroads to approach their termini above ground thus avoiding the tracks creating an impermeable barrier that cut through neighbourhoods. This could have also been done by putting the tracks below ground, and having street continuity with bridge above the tracks, but particularly south of the Thames, marshy land often resulted in viaducts rather than cuts.

There are up to ten thousand arches created by the masonry construction of the viaducts, and many of them have been used since their creation for a variety of mostly commercial and industrial uses. It was originally thought they might be used for housing, but there was too much noise, pollution and vibration. They were used for functions such as stables, storage and other marginal uses. More recently, their uses have been service or small-scale industrial functions of various kinds, including auto-repair shops, taxi services, storage facilities, crafts relating to furniture and woodworking, sheet-metal fabrication and other businesses that tend
not to require the same kind of visibility as retail shops on high streets. Indeed, the rows of arches—and their businesses—are often seen at the “edges” of neighbourhoods rather than at their centres. Despite this, space syntax analysis of arches in three locations in London (Bermondsey, Bethnal Green and Hackney) found that the arches had relatively high choice and integration values compared to their surrounding urban fabric, perhaps because tunnels through the arches open them up to local movement (Froy and Davis, 2017.

In recent years, the economic value of the arches—which in London are largely owned by Network Rail—has increased, and in some places the arches are beginning to house businesses of the new “creative economy” as well as cafés and restaurants. Like many old industrial and warehouse buildings, the arches have gained an aura of “edginess,” favoured by entrepreneurs and customers who like their basic masonry construction, which is often unfinished on the inside except for a coat of paint, as well as the fact that their interiors may be completely visible from the outside.

The arches have traditionally been managed by the quasi-public entities Network Rail and Transport for London, who have set rents relatively low. However more recently there has been an attempt to extract more value from the arches to invest back in the wider rail infrastructure. The rent rises threaten to force out older, secondary businesses to make room for the creative, production and leisure-oriented businesses of the “new economy” who can afford to pay more. But even so, the railway arches tend to be cheaper to rent than buildings on nearby streets.

The business owners in the three case study locations in London were found to be taking advantage of the ‘modular’ spaces provided by the arches - for example, the London Fields Brewery in Mentmore Terrace, Hackney, owns a number of adjacent arches, each being used for a different type of activity. They host brewing facilities for thirteen varieties of local beer, a small bar, a larger beer hall and concert venue, and an office (constructed as a mezzanine). Further along Mentmore Terrace, the E5 Bakehouse used to use its next door arch for grain milling, but has now opened this up into a second café/restaurant space. In Bermondsey, the Neal’s Yard Dairy on Druid Street uses two arches side by side, one for the maturing of cheeses, and the other as office accommodation.

The study found that there was a relatively high degree of communication between the firms using the arches in the case study areas. Communication was most frequent with immediate neighbours (cited by 21 businesses), but was also present between a larger set of firms in the arches (21 businesses) and in the surrounding locality (9 businesses). Only two firms said that they had no communication with the firms around them. Types of cooperation included sharing and using each other’s products, making referrals and helping out in a crisis. There was also evidence of the benefits of local networking to support business start-ups. The owner of the E5 Bakehouse in Mentmore Terrace, for example, benefitted from initially being able to set up a kiln to start baking at the ‘Happy Kitchen,’ a wholesale-oriented firm that operates from an arch a few doors down. The Happy Kitchen itself initially started up in a business incubator at the Westgate Centre, only a few streets away.

The arches and their spatial configurations have a number of attributes that are relevant to our investigation:

1. Although property values are rising—and along with them the rents of the spaces in the arches—the arches operate within a cheaper ‘parallel rental market’ run by Network Rail and Transport for London. Rents are in particular depressed because the arches are not sought after as residential locations. In Jane Jacobs’s terms, they are “old buildings,” and useful because they provide space for businesses that cannot pay larger rents, but that are nonetheless essential to the local economy.

2. The arches are often directly opposite housing, and particularly social housing. Since social housing is often segregated from the surrounding urban fabric, the arches suggest the possibility of economic relationships between the businesses and the social housing.

3. They are flexible in their use and exist in a variety of sizes, as the width of railway viaducts vary, and as varied sizes and configurations, even in a particular location, exist when two
viaducts combine into one. The spaces are simply formed with brick or stone, allowing for permanence and sense of “toughness”, but also allow for partitions, lofts and balconies, and varied ways of designing and building the wall to the outside.

4. They have a linear arrangement, with a direct relationship to the pedestrian or vehicular realm often without a footpath or space for cars to park. Where they contain industrial functions they form “industrial streets”, that are very different to more hierarchical and segregated industrial estates. These “streets” act like most city streets do—they allow for interaction among the businesses that are along them; and they also allow for visibility and access to the public.

The arches are sometimes relatively small compared to much industrial or retail space in the city, but they form an important part of what we suggest is a necessary hierarchy of spaces for industrial and creative uses. The arches are visible, well-connected to street networks and appealing to various types of entrepreneurs. Jane Jacobs would likely have seen them as spaces with the potential to play an important role in the creative functions of a city.

Figures 1 and 2 - Railway arches as commercial spaces

2.1 WINKLEY ESTATE: A MIXED INDUSTRIAL AND HOUSING ESTATE

The second case study is a four block estate in the Bethnal Green neighbourhood of London. The Winkley Estate, as we call it, was built by the property developer Charles Winkley around 1900. Although it was designed and built as a single integrated development, it is unusual in that it consists of a variety of different building types, housing a variety of functions. It incorporates two and three story terraced houses without spaces dedicated to commercial or industrial uses, three story terraced houses with retail shops on the ground floor, three story terraced houses with workshops occupying the ground floor and a basement below, blocks of flats served by stairs that give access to two flats at each landing, and factory buildings with large open spaces on each floor (see Figure 3).
In addition, the estate includes two-story workshop buildings in the interior of the blocks, located between the house terraces that face outward to the streets. These workshop buildings are accessed from yards that are themselves accessed by means of passages through the house terraces. Although the project is quite dense, each house has outdoor space, and because some of the terraced houses are raised up above shops or workshops, they have quite adequate daylight.

The spatial and functional variety is accompanied by a great deal of flexibility in the ways that the different spatial units can be connected to each other. For example, the two-story workshops that are underneath the two-story terraced houses on Temple Street may be accessed independently from the street, or internally from the stair leading up to the residence. This allows the workshop to be rented independently or used by the family living upstairs. Likewise for the buildings on Old Bethnal Green Road—the retail shops have internal doors leading to the residential stairs, allowing for the same kind of flexibility. This is a typical arrangement for shop/houses, but it is perhaps unusual for industrial or workshop space. The workshop spaces have good levels of daylight and all the units apart from the flats have outdoor space in the form of roof terraces. Space syntax analysis reveals that a communal yard space is highly central to many of the workshop units (see Figure 3 below), offering a space for co-presence and encounter.
But perhaps most interesting are the spatial relationships regarding the internal ranges of workshops—internally and in their relationships to adjacent dwellings. First, these buildings have two adjacent entry doors—one leading to the ground floor, and the other leading to the stair. This allows for the workshops to be rented separately or together. In addition, some of the workshops may be accessed either directly from a public yard or from the private back area that is connected directly to the house. This allows for more flexibility in the connectivity of the workshops.

When the estate was built, and for several decades thereafter, Bethnal Green and the adjacent neighbourhood of Shoreditch together comprised one of the centres of the furniture industry in London. The industry was made up of thousands of very small shops, each housing a particular, specialised craft. These included frame makers, joiners, upholsterers, polishers, carvers, turners, as well as various suppliers of wood, oil, tools, fabric, furniture hardware and upholstery trimmings. These individual businesses often acted as subcontractors to wholesalers who sold their products to retailers all over London and outside the city. Working with the retailers, the wholesalers were directing the manufacturing process in what may be considered a flexible, open system, that changed from one furniture order to the next, employing different combinations of individual craftsmen. The organisation of the industry within an organically-developed local urban morphological structure, is shown by another paper at this conference. In this system, proximity of the shops was important. Although the Winkley estate was designed all at once, it has a similar spatial structure to the organically-developed neighbourhood around it.
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### Table 1 - Businesses in the Temple and Crown Yards at Winkley Estate in 1910 and 1940

<table>
<thead>
<tr>
<th>1910</th>
<th>1940</th>
<th>present</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cabinet makers</td>
<td>Cabinet makers</td>
<td>Designers</td>
</tr>
<tr>
<td>Boot manufacturers</td>
<td>French polishers</td>
<td>Architects</td>
</tr>
<tr>
<td>Chair maker</td>
<td>Table makers</td>
<td>Artists</td>
</tr>
<tr>
<td>Wood carvers</td>
<td>Show case makers</td>
<td>Video production</td>
</tr>
<tr>
<td>Tailor</td>
<td>Mirror maker</td>
<td>Map maker</td>
</tr>
<tr>
<td>Upholsterer</td>
<td>Wood carver</td>
<td>Furniture maker</td>
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<tr>
<td>Basket maker</td>
<td>Chair maker</td>
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<tr>
<td>Antiseptic amonia seller</td>
<td>Upholsterers</td>
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<tr>
<td>Pub</td>
<td>Wood turner</td>
<td></td>
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<tr>
<td>French polisher</td>
<td>Printers</td>
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<tr>
<td>Printers</td>
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Source: London Street Directories

London street directories show that many workshops in the Winkley Estate were used for the various crafts of the furniture industry for several decades after the project was built (see Table 1). The four blocks escaped much bombing during the Second World War and the buildings are now used for the so-called “new economy” including spaces for designers, architects, artists, video production companies, a map maker, a furniture maker and other similar. One retail space, directly on Old Bethnal Green Road, houses an architect’s office that also runs a café at the front.

The Winkley estate exhibits the following attributes that are relevant to our discussion:

1. There is a considerable range of sizes of work spaces, ranging from whole floors in the factory buildings (in which two or more floors can be combined for a single business) down to a single floor in the workshops that are in the yards behind the terraced houses.

2. There is flexibility in connections between work spaces and dwellings, and between work spaces themselves. This allows for businesses to expand and contract, and for relationships between businesses, and between businesses and dwellings, to evolve over time.

3. There is density and consequent proximity, setting up spatial affordances to possible economic relationships.

4. Although property values and rents are rising, as they are all over London, they are still lower than they are in other places in the city—and the availability of very small spaces in these old buildings means that although rents per square meter may be high, the spaces themselves are still affordable to start-up businesses without a great deal of cash flow.

Gillett Square: bringing community and enterprise use of a public square together

Our third case study is Gillett Square in the London neighbourhoods of Dalston. Gillett Square is a public space that is the result of a bottom-up process of conceptualisation and design, that was built over about twenty years. Located near the Dalston Kingsland Overground station and the Ridley Road Market, it was built on the site of a former car park that was itself located on the space formerly occupied by terraced houses on either side of Gillett Street.

A local organisation, Hackney Cooperative Development (HCD), took the lead in organising the financing, approvals, and neighbourhood politics required for the project. The project happened in a series of stages that included the following:
1. The renovation of a row of terraced-houses-with-shops on an adjacent street. This renovation allowed startup businesses to occupy the shops, eliminated the inside stairs, and put outdoor galleries for access to the upstairs rooms on the back, facing what would become Gillett Square. These upstairs rooms are rented to very small businesses and to the offices of local cultural organisations.

2. The renovation of an old clothing factory into the “Dalston Culture House” that now houses the Vortex Jazz Club and a café.

3. The design, by means of a competition, of a series of small prefabricated metal kiosks, that were placed outside the backs of the terraced houses and facing the square. These kiosks are rented to small businesses that include a juice bar, a recording studio, a local radio station, a tailor, an international money-transfer service, and similar businesses.

4. The paving of the square itself, to make it suitable for informal pedestrian activity, a place for children to play, as well as a place for concerts and performances of all kinds.

5. The reuse of a factory on the north side of the site, to make it suitable for spaces rented to various small businesses and a social housing organisation.

Figure 5 - Gillett Square, Showing The Dalston Culture House On The Right, The Backs Of Renovated Terraced Houses And The Prefabricated Business Units On The Left.
The square is located within sight of and about 50 meters from the Kingsland High Street, which is the continuation of the Kingsland Road to the south and the Stoke Newington Road to the north. It has public access from the Kingsland High Street, from Boleyn Road to the west, and from Bradbury Street, along which are located the renovated terraced houses that are a part of the scheme, to the south. The square thereby connects a residential district with an important high street. In this respect, Gillett Square is connected to its surroundings much more strongly than the usual London residential square that is typified perhaps by Lonsdale Square in Islington, the lack of connectivity of which was shown as an example in Hillier and Hanson's The Social Logic of Space. Indeed, Gillett Square is much more typical of squares on the European continent which are at or near the crossroads of important streets.

Gillett Square has been highly successful. The Vortex Jazz Club is one of the best jazz venues in London, with internationally known performers. The radio station and recording studio are the source of music heard far beyond the square. The square itself is the site of programmed performances of all kinds—dance, music, theatre, mixed performances of various kinds— as well as spontaneous, unprogrammed artists, and was one of the sites for the handover of the Olympics to Rio de Janeiro at the end of the London games in 2012. People come there for informal mingling as well as for scheduled performances. It has turned out to be a place of cultural and artistic innovation, with a strong mixture of performers, cultural entrepreneurs, along with start-up and established cultural organisations.

In summary, Gillett Square has the following attributes that are relevant to this paper:

1. It was built through a bottom-up process, gradually over about two decades. This process necessarily involved many different participants, political entities, and sources of funding. Although Dalston is gentrifying, the square—the land of which is held by HCD in a 99-year lease—is seen by many people in the neighbourhood as a bulwark against gentrification.

2. The square is near important centers of Dalston, including the Dalston Kingsland and Dalston Junction Overground stations, the Ridley Road Market, and the Kingsland Road/ Kingsland High Street/ Stoke Newington Road high street. It is visible from the high street and helps form a link between the high street and the residential neighbourhoods to the west. It would seem therefore to be both locally and globally connected.

3. The square incorporates buildings of different sizes and ages, including old buildings that have been minimally changed, old buildings that have been substantially reconfigured, new buildings built on site, and new prefabricated buildings that were delivered and installed on site. These buildings incorporate a wide variety of cultural uses, often by organisations and businesses with a minimum of capital. Although some housing was built on the square, it is not regarded to have been successful as it is affected by the noise of cultural events—the square is more a shared commercial and public/community space.

We hypothesise that these characteristics help the square develop and maintain its status as a place of artistic innovation. It provides a wide range of spaces for creative performing artists, puts them together in the same place, and allows them to rub shoulders with people from the neighbourhood and city that support them financially and help disseminate their artistic products.

3. CONCLUSIONS

This article has today as the risk of gentrification and the loss of commercial space is ever present. The rental values of railway arches are on the rise in parts of London, while industrial areas such as the Winkley Estate are gradually converting to residential uses. In the UK this year, amendments to the Town and Country Planning Order will soon create a new permitted development right to allow conversions from light industrial (Class B1c) to residential (Class C3). This is despite the fact that urban manufacturing is increasingly prized. Froy and Davis (2017) point out that within the ‘postfordist’ economy, industry is being attracted back into inner city areas, with production often being cleaner, and requiring less space than before. As production has reemerged in cities, theorists have noted a blurring between manufacturing, design and
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retail, leading to the creation of hybrid forms of urban enterprise (Coyle, 2001, Evans, 2009). All this means that a “mixed-use” approach may be increasingly appropriate, in which factories and shops are intermixed, and located near residential areas.

The case studies illustrate the benefits of adaptability and flexibility, and of relative low-spec adaptable commercial spaces that can be added to in a modular fashion as businesses expand. The Winkley Estate workshop spaces, for example, have proved adaptable to both craft and design uses over their history. When designing commercial spaces, relatively low-spec spaces may be particularly sustainable in adapting to new uses over time. As Hillier (1999) points out, ‘form changes only slowly while function changes rapidly’ (p.126), and commercial spaces need to be designed with this in mind.

Further, the three case studies show the benefits of designing commercial spaces in a way that encourages collaboration. In the case of the railway arches, the openness of the facades and the location of the arches in ‘industrial streets’ encourages communication between the hosted businesses. In the Winkley Estate, the yards provide semi-public spaces which may encourage interaction, complemented by the presence of cafés. In Gillett Square the location of commercial and artistic production spaces on a public square encourages mixing with local people. While in the latter case, collaboration was stimulating creativity within the arts, all three case study examples point to the importance of commercial spaces that promote synergies and creativity within other types of production and retail, contributing to Jacobs’ broad vision of the ‘creative city’. The levels of new product innovation within such neighbourhoods and within different commercial spatial forms could well be the focus of future research.

The case studies have also illustrated the value of bringing manufacturing into residential areas. The integration of spaces where manufacturing takes place with social and residential space renders the processes, skills and tools used in manufacturing visible. This visibility makes the connections between people and the products they use and consume more tangible and understandable, which has become obscured due to manufacturing been relocated outside of major populations centres or abroad (in the majority of economically developed countries). The integration and visibility of manufacturing also acts to demystify the processes of production and alert people to the possibilities of also engaging in manufacturing, whether as a cottage industry simply equipped with a sewing machine, woodworking with a set of chisels or prototyping ideas for objects with 3D printers. These small-scale explorations of manufacturing can then potentially open the way for wider participation and understanding of manufacturing processes. This holds promise for those policy makers hoping to promote inclusive growth in cities (Green et al., 2016, RSA, 2016) through opening up the benefits of entrepreneurship and economic participation to a broader section of the city population.

A common criticism of high-end urban manufacturing industries is that they are fundamentally a niche phenomenon and are unlikely or unable to grow to a size that makes a major contribution to the economy. Moretti (2012) suggests, for example, that urban manufacturing usually ‘piggy backs’ on highly skilled knowledge economy work in cities, which provides the salaries necessary for people to indulge in expensive niche products. Whilst this is a valid criticism, it seems to ignore the long history of wealthy individuals who have acted as patrons to craftsmen and artists. This patronage is similar to the phenomenon that we see today, and whilst primarily supporting high-end manufacturing, has potential trickle down effects, encouraging the growth of new sectors, or revitalising nascent old ones.

In each of the case studies it was clear that the economic activities examined were embedded within much broader economic networks, and that this may be being supported by spatial linkages or ‘stitches’ to the broader urban fabric, for example through proximity to major city routes. In this respect, it would seem to be important not to focus too closely on creative districts and innovative urban milieux (Hall, 1998, Hessler and Zimmerman, 2008) without understanding how they are ‘stitched into’ broader economic and spatial networks of the city as a whole. Space syntax can contribute here by pointing towards the importance of local-global spatial linkages, and this is an area for further exploration. For example, the Winkley Estate seems well-connected into the city of London via the Old Bethnal Green Road, but detailed
analyses can confirm this. Gillett Square is also close to major city routes, such as Kingsland High Street and appears to be a strong connector between that street and the residential areas to the west. In addition to analysis of the street configuration, it would be useful to undertake detailed analyses, possibly involving convex maps, of the square itself, to understand local linkages between its different uses. The railway arches, despite sometimes seeming relatively segregated, were also bringing production into relatively central city areas. The impact of this could also be further explored.

More broadly, in the future it would seem fruitful to further develop Jane Jacob’s ideas of the spatiality of economic development, to understand the urban morphologies associated with creative and productive cities. Does the global spatial organisation of street networks in some cities make them particularly likely to support self-generating economic growth? If so, how might this be examined and theorised?
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#63

A COMPREHENSIVE APPROACH TO URBAN UPGRADING:
The role of space and architecture in Medellin’s ‘Urban Integral Projects’ (PUI).

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ABSTRACT

In recent years the transformation of Medellin has led many urban agencies, media experts and academics to praise its strategy for urban upgrading. Areas of informality are sympathetically incorporated into a citywide transformation process, resulting in a series of interventions aimed at improving rather than eradicating informal settlements. This developed into a much talked about ‘comprehensive’ approach to urban upgrading, where elements like transport infrastructures, educational facilities and public space would be grouped together to maximize the individual impact of each intervention. This was realized through the Integral Urban Projects, or PUI (Proyectos Urbanos Integrales). The most eye-catching element of these would often be the Library-Parks, a combination of a library building and generous surrounding and indoor spaces for public use. These were developed to address the need for more cultural and education space in poor neighbourhoods and are architecturally designed to a high standard. These aim to be the centre of each community and the focal point for transforming poor neighbourhoods, helping to legitimize parts of the city that were once no go areas. However, the role of the existing street network in the distribution of these interventions is often unclear, or ambiguous at best. As a result, there is a need to understand how these interventions connect to the existing street network, to appreciate if the projects at the heart of this urban strategy are really responding to the existing urban fabric.

Therefore, this paper analyses how Medellin’s Library-Parks are spatially distributed throughout the city, examining whether or not there are identifiable spatial patterns that allow them to become the centre of each community. To do this, the relationship between ‘to’ and ‘through’ spaces is analysed for each Library-Park location, at both local and meso scales. These results are used to categorize the Library-Parks in terms of how well they are syntactically connected to local and global centres, thus highlighting the Library-Parks that are centrally located. This then allows a selection of Library-Parks to be looked at more closely, so as to illustrate the interrelation between urban ambitions, their architecture and their use of transport infrastructures. This analysis provides an opportunity to discuss their role within Medellin’s PUI projects and how this connects to the city’s ‘comprehensive’ urban approach. This paper is about understanding how certain spatial ambitions within the ‘comprehensive’ approach to upgrading areas of informality were actually realised in Medellin and how this relates to its much-hyped urban discourse – the ‘Medellin Model’.
KEYWORDS
Medellín; Informality; Library-Parks; Comprehensive Urban Upgrading.

1. INTRODUCTION: THE URBAN STRATEGY OF MEDELLÍN
Cities in Latin America grew exponentially in the first half of the 20th century, due to intense industrialization and rural migration (Echeverri and Orsini 2010, 148). This growth resulted in many urban issues, particularly a widespread informal growth (Fiori, Riley, and Ramirez 2000; Brakarz, Greene, and Rojas 2002). In general, these informal areas lack basic infrastructure and correspond to the most violent places in the cities (Echeverri and Orsini 2010, 131). The Latin-American governments’ first attempt to resolve these problems was to reallocate the urban poor to the edges of the cities, using coercive force as their mean to eradicate urban informality (Echeverri and Orsini 2010, 136). However, the last quarter of the 20th century saw the emergence of a new strategy: that of the improvement (or ‘upgrading’) of the existing poor urban settlements (Turner 1972; Turner 1976; Fiori, Riley, and Ramirez 2000; Brakarz, Greene, and Rojas 2002; Echeverri and Orsini 2010, 136). Medellín is considered by many urban agencies, media experts and academics as a successful case of the ‘urban upgrading’ strategy.

Echeverri and Orsini (2010) highlight that the shift of planning strategy – from coercive actions that aimed to reallocate inhabitants of poor areas, to the improvement or ‘upgrading’ of these areas – is one of the reasons for the success of the Medellín Model. The authors explain that the coercive strategies were inefficient because they did not address the origin of the problem. Governments spent time and public resources in repressive actions that were incapable of providing housing and infrastructure for the population, or including these communities within the formal city. Echeverri and Orsini (2010) posit that the ‘urban upgrading’ strategy is opposed to the ‘coercive’ ones as it sees the urban informality as a solution, rather than a problem. This fundamental shift in how to approach urban informality was originally proposed by Turner (1972; 1976). His numerous contributions as to how governments, social agencies, public and architects provided the ground to the formulation of the ‘urban upgrading’ project, which should focus therefore on the (participative) provision of infrastructures, buildings and programmes that could improve, rather than eradicate, urban informality.

Among the main strategies utilised in the project of ‘urban and social upgrading’ in Medellín, one may include: firstly, a transport strategy, with the implementation of the ‘Metrocables’ (aerial cable-cars), which enabled access to the main metro line to populations of underprivileged areas of the city. Secondly, the construction of social housing projects in the same neighbourhoods. Thirdly, public libraries of ‘great architectural impact’ were built (namely the Library-Parks Project), which offered a wide range of services to the surrounding communities. Fourthly, the programme of urban upgrade included the renovation of schools and other public facilities. A fifth and last strategy refers to the urban public space renovation, connecting all projects so as to expose the integration of investments. Moreover, the projects in Medellín are referred to follow a strategy of urban renewal named ‘urban acupuncture’, which promotes the idea that an urban area can be entirely affected by small, but precise, operations in very specific locations (Peña Gallego 2011). The interventions were linked administratively by the “Proyectos Urbanos Integrales” (‘Integral Urban Projects’) and coordinated by the ‘Company of Urban Development’ (‘Empresa de Desarrollo Urbano’, EDU), which is a state-led institution.

The most eye-catching element of these would often be the Library-Parks, a combination of a library building and generous surrounding and indoor spaces for public use. These were developed to address the need for more cultural and education space in poor neighbourhoods and are architecturally designed to a high standard. These aim to be the centre of each community and the focal point for transforming poor neighbourhoods, helping to legitimize parts of the city that were once no go areas. However, the role of the existing street network in the distribution of these interventions is often unclear, or ambiguous at best. As a result,

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1 One of the mayors of Medellín emphasized the importance of architectural quality in these projects, formulating that their aim was “to activate the power aesthetics as a motor for social change” (Salazar apud Brand and Dávila 2013).
there is a need to understand how these interventions connect to the existing street network, to understand if the projects at the heart of this urban strategy are really responding to the existing urban fabric.

Therefore, this paper analyses how Medellin’s Library-Parks are spatially distributed throughout the city, examining whether or not there are identifiable spatial patterns that allow them to become the centre of each community. To do this, the relationship between ‘to’ and ‘through’ spaces is analysed for each Library-Park location, at both local and meso scales. These results are used to categorize the Library-Parks in terms of how well they are syntactically connected to local and global centres, thus highlighting the Library-Parks that are centrally located. This then allows a selection of Library-Parks to be looked at more closely, so as to illustrate the interrelation between urban ambitions, their architecture and their use of transport infrastructures. This analysis provides an opportunity to discuss their role within Medellin’s PUI projects and how this connects to the city’s ‘comprehensive’ urban approach. This paper is about understanding how certain spatial ambitions within the ‘comprehensive’ approach to upgrading areas of informality were actually realised in Medellin and how this relates to its much-hyped urban discourse – the ‘Medellin Model’.

2. THE PROJECT OF LIBRARY-PARKS

The ‘Library-Parks’ are public facilities that were built to foster educational, cultural and social practices of their surrounding neighbourhoods (Peña Gallego 2011; Rodríguez, Valencia, and Arias 2013), as well as act as local centres of ‘community encounter’ (Figures 1 and 2). In fact, the organisers of the ‘Library-Parks Project’ claim that ‘co-inhabitation’ is the raison d’être of these buildings (Fajardo Valderrama 2007; Montoya 2014). Considering that the Library-Parks are situated in neighbourhoods that are historically and culturally developed through incremental growth and self-management (Arciniegas 2014), a first question that arises is how these two conditions are manifested in the Library-Parks, particularly in relation to the organisation of their spaces. The idea of knowledge is embedded in libraries (Forgan 1986; Markus 1993; Koch 2004) through the organisation of architectural space and access to informational content. Similarly, we discuss elsewhere how collective values are part of the structuring of spatial and social relations in public library buildings (Capillé and Psarra 2014). In regards to the particular case of Medellin’s Library-Parks, we developed a process to capture and describe how their interior morphology frames collective use so as to embed significant political roles (Capillé 2016; 2017). In the present paper, we aim to expand this argument, discussing the social potentials that emerge from these libraries’ position in the urban grid.

All Library-Parks’ designs were winning schemes of open international architectural competitions (Montoya 2014). The organisers of the Project of Library-Parks (Montoya 2014; Empresa de Desarrollo Urbano 2014) explain that the competitions were open with the intention to endorse the participatory character of the construction of these facilities. The brief presented for the competitions requested a “building for multi-services, library, classes for adult qualification, exhibition room, administration spaces, and auditorium” (Empresa de Desarrollo Urbano 2014). The brief also emphasised the social importance of these facilities. Beyond the ‘mere’ function of a library (to organise and provide access to a collection of books), these buildings have the role to strengthen community values and provide spaces for emergence of socialisation based on informal interactions (Montoya 2014). This aspect was fundamental for the creation of the Library-Parks, in the view of the organisers of the Project, and it was strongly associated with these buildings’ provision of public spaces, which integrates them with their surrounding urban flows.

Peña Gallego (2011) explains that the Library-Parks are obliged by law to provide a number basic of services, for example: direct access and external lending of books, foster education of users, improve literacy, educate for ‘digital literacy’, access to the internet, etc.. In addition to these basic services, the libraries also provide complementary ones, for example: they host plays, exhibitions, fairs and workshops, they have a cafe and provide spaces for children to play.

The Project is part of a greater Programme of digitally connected libraries (‘Red de Bibliotecas’ and ‘Medellín Digital’), which offers open access to a wide range of resources online, from books, to videos and other forms of digital content. In this sense, the Library-Parks can be considered as integrated within a digital programme.

Aside this ‘digital integration’, the libraries are also spatially integrated in their urban contexts. The Library-Parks are linked administratively and spatially by the “Proyectos Urbanos Integrales” (‘Integral Urban Projects’). In some cases (particularly España Library-Park, Figure 2a), the library buildings are surrounded by other interventions of the Project of Urban Upgrading (e.g. schools, cable-car stations, new public spaces, etc.). Moreover, and as we mentioned above, the projects in Medellín are referred to follow a strategy of urban renewal called ‘urban acupuncture’, which promotes the idea that an urban area can be entirely affected by small, but precise, operations in very specific locations (Peña Gallego 2011). In other words, their ‘urban impact’ would expand to areas that are distant to their specific locations.

In this sense, the libraries acquire a significant political role beyond their educational agendas that stimulate appropriation and participation (Capillé 2017). These buildings would use their urban locations as means to affect an entire community. However, the extent of the ‘urban impact’ of the Library-Parks’ position in the city was not yet analysed in depth. Such an analysis could provide interesting information with regards to placing public architecture in informal environments and to how these buildings are integrated in the existing urban culture. This paper advances a small contribution in this regard, particularly considering the spatial structure of the urban grid as a way to characterise and differentiate the Library-Parks in terms of their urban and political potentials.

Figure 1 - Map of the location of the Library-Parks in Medellin (black circles) and the lines of Metro and Metrocables (dotted lines) and their stations (black squares).

In English, ‘Network of Libraries’.
In English, literally ‘Digital Medellín’.
3. METHODOLOGY

In order to understand the spatial distribution of Medellin's nine Library-Parks they are each located within a previously developed spatial model of Medellin's metropolitan area (Goodship 2015), Figure 3. Once located within this model a 1000m radius is formed from the centre of each library-park to create a zone of analysis (Figures 7, 8 and 9). This distance represents a reasonable walking distance for user of the library-park, since they are for local use.
Within this zone of analysis, three main spatial measurements are studied. First, Normalised Integration (NAIN) – normalised measurements are used to enable accurate comparison between different locations (Hillier, Yang, and Turner 2012) – this demonstrates the most important ‘to’ space. Second, Normalised Choice (NACH), this determines the most important ‘through’ space. Finally, the correlation between ‘choice’ and ‘integration’ measurements is examined, since this represents the likeness of the area having qualities of centrality, which could generate contact (Vaughan, Dhanani, and Griffiths 2013). Each of these measurements will be examined through a range of metric radii to examine the connectivity of each library at different urban scales.

The results from these three measurements will then be used to select three libraries to examine in more detail. This will select the library with the best, the worst and the mid-range results, using the metric radius 2000m. We will then analyse the location of each selected library, highlighting their surrounding amenities and urban fabric. This will enable the final part of the paper to examine how the Library-Parks actually relate to the urban upgrading discourse of Medellin’s PUI program.

4. RESULTS

The Library-Parks are generally distributed across the poorest regions of the city, usually within the socioeconomic band of 1, 2 or 3 (figure 4). Colombia’s socioeconomic banding is between 1 to 6, with 1 being the lowest and 6 the highest. It is also worth pointing out that the Library-Parks only appear within the municipality of Medellin, not neighbouring municipalities that form the city’s metropolitan area. This is a consequence of each municipality being governed separately, even though in recent times the 10 municipalities that form the metropolitan area have spatially merged into one city.

Starting with the ‘to’ space analysis, when the average NAIN values for each library-park zones is examined, in general each Library-Park has its highest average values at the lowest metric radii, which represents the local scale (Figure 5). This is the urban scale at which the Library-Park is aiming to connect with and have its largest influence within the upgrading process. These average values steadily drop the higher the metric radii increase until their reach 5000m, at which point they plateau.
The Library-Park with the highest average NAIN values throughout is Guayabal, with both Belen and La Ladera also featuring high in the list. This is mainly because these Library-Parks are positioned centrally to the city, so when the analysis measures the whole city, a central location will provide better values to these locations since integration is strongest in the centre of the city. The Library-Parks with the lowest average values are San Cristobal, Espana and Jose Betancur, however whilst San Cristobal and Espana have low values throughout the metric radii, Jose Betancur has high values at low metric radii, indicating strong ‘to’ space at a local scale, these then rapidly drop as the metric radius increase.

Next, ‘through’ space is analysed using the average NACH values for each Library-Park. As with the NAIN results, each library generally has its highest average values at the lowest metric radii, between 500m and 750m. These average values steadily drop the higher the metric radii increases. However, unlike the average NAIN values, these are much closer together throughout. In general, the Library-Parks with the highest average NACH values throughout is La Ladera, San Javier and Belen. However, Jose Betancur is generally high on the list until the metric scale of 3500m, when it rapidly drops to one of the lowest. In general the lowest average NACH values throughout is San Cristobal, La Quintana and Doce de Octubre.

Figure 5 - Average NACH and NAIN spatial values.
These average values indicate that the Library-Parks are usually positioned in the local network and engage with the spatial network at a local scale, which is generally what one would expect for a local library.

Another reach of spatial values worth examining for each Library-Park is the correlation between choice and integration (Figure 6). This measurement traditionally determines how 'strong' the urban centre is for each scale. Hence, with the ambition of the Library-Parks to form a part of strong urban centres for the local community, this correlation is worth exploring.

The INT-CH correlations, as per the previous results, again indicate it is at a local scale that the highest correlations exist, this again drops off the larger the metric radii gets. In general Guayabal has the highest correlations, with both San Cristobal and Jose Betancur showing the next highest correlation, though Jose Betancur has very low correlations at local metric radii. The Library-Parks with the lowest correlations are La Ladera, Belen and Espana. A strong correlation coefficient is usually defined as above 0.7 r/2 (Rowntree 2000), at this size of analysis there are only a small handful of metric radii with this value and all are within Guayabal. However, when the analytical zone is reduced to a 500m radius, the correlation coefficient values increase and four Library-Parks have at least one metric radius with a high correlation. This is an indication that the Library-Parks are centrally positioned at a local scale.

Figure 6 - Choice-Integration Correlations.

While this represents a good basic understanding of each Library-Park, it should be noted that these are the average values for all the segments within an analysed zone, thus this may not provide an accurate spatial analysis for each library. Therefore, as previously mentioned, three libraries are selected from this initial analysis for closer examination. The Library-Park with the highest values throughout is Guayabal, the lowest values are La Ladera and mid-range values are La Quintana. Conveniently, these 3 Library-Parks each represent a different area of the city and all avoid the problems of edge-affect.

4.1 GUAYABAL

Starting with the Library-Park that has the highest spatial values, Guayabal (figure 7), it is very clear that it is well positioned close to important ‘through’ routes, one of which is the main city highway. These north-south roads provide important routes through the city, as well as the main route in and out the city. As a consequence these are important ‘through’ spaces at a city scale. However, at a local scale ‘through’ space also appears positive. This Library-Park also has reasonably high ‘to’ spaces, with very few low integrated spaces, even though the local airport opposite splits the analysed zone into two.
In terms of near-by public facilities mapped using data supplied by the municipality, this indicates that 46% of the land within the analysis zone is dedicated to public facilities, however much of this is taken up by the airport. When the airport is removed from the analysis it drops to 16%. The public facility that takes up the most space is sport, then cultural facilities (which the Library-Parks fall in) and thirdly municipal institutions. In terms of the total number of public facilities there are 45, of which education is the highest with 9, then sports with 8, and thirdly community buildings with 7.

With the socioeconomic bandings, the largest area in Guayabal falls within the Colombian socioeconomic band 4, accounting for 77% of land, the next highest is band 3 accounting 22%, then band 1, 2 and 5 account for less than 1%. If we look at land value within this area, 93% of the land is valued above 500,000 Colombian pesos sq/m (1000 Colombian pesos equal US$0.34), with 5% between 400,000 and 500,000 and rest below 400,000. Both land values and socioeconomic banding are high for Medellin, which is most likely a result of its position next the airport, which is increasing the average results. Finally, looking at the morphology of the building heights, we see that 48% of buildings are one storey high, 30% two storeys, 16% three storey and 4% four storeys, the other 2% is five or above storeys.

Figure 7 - (a) Guayabal’s NACH 2000, (b) Guayabal’s NAIN 2000, (c) Guayabal’s land use, (d) Guayabal’s socioeconomic strata, (e) Guayabal’s land value, (f) Guayabal’s building heights. Credit of photograph: (Alcadia de Medellin and Empresa de Desarollo Urbano 2015)
4.2 LA QUINTANA

La Quintana is the library that sat in the middle of the results (figure 8). Similar to Guayabal, it is well positioned next to important ‘through’ routes, which run west-to-east towards the centre city. Yet there is also useful ‘through’ routes throughout the metric-radii, and especially at a local scale. However, unlike Guayabal, most of this Library-Park’s neighbouring areas do not serve as good ‘to’ spaces, especially around the peripheral zone of the selected area for analysis, and is most dominant between the metric-radii of 2000 and 5000m. This is a result of the periphery becoming more informal and less connected to the area directly surrounding the Library-Park.

In terms of land use surrounding the library, the results indicate that 14% is dedicated to public facilities. Among these, educational facilities represent 43%, healthcare represents 35% and places to worship represent 8%. There are 93 public facilities in total – more than double of Guayabal’s number. With regards to socioeconomic conditions, the largest percentage of land is within band 2 (48%), then band 3 (30%), band 4 (15%) and band 1 (6%). In terms of land-value, the analysis indicates that 41% of the land is valued between 300,000 and 400,000 pesos sq/m, and then 16% of the land is above 500,000 and 15% between 200,000 and 300,00. These two indicators show that this area maybe considered poorer than Guayabal. In regards to the morphology of the building heights, the analysis shows that 36% of the buildings have two storeys, 30% three storeys, 24% one storey and 5% fours storeys, the remaining 5% account for buildings that are five or above storeys.
4.3 LA LADERA

La Ladera is the Library-Park with the lowest values for ‘through’ and ‘to’ movement (figure 9). Its surroundings present reasonable ‘through’ space, which connects to the city centre. However, the Library-Park itself is set back from these paths, with no direct connection. Similar to the other two selected Library-Parks, surrounding ‘through’ spaces function at a variety of urban scales. However, the ‘to’ spaces analysed in this area are affected by the fact that much of this neighbourhood is informal and segregated from the formal areas. Hence, this Library-Park is situated in an informal area that is spatially segregated from other parts of the city.

In terms of near-by facilities, 21% is dedicated to public facilities (97 buildings in total), such as educational buildings and public services (e.g. an energy plant, water storage, fire station, and police stations). In regards to socioeconomic conditions, the largest percentage of land lies within band 3 (58%), followed by band 4 (25%) and band 2 (17%). The land-value analysis show 38% of the land valued less than 100,000 peso sq/m, then 26% of land is valued between 400,000 and 500,000 and 24% below 200,000 and 400,000. This analysed zone represents two very different types of urban space, one informal and the other formal. These contradictory urban form results in hugely differing results, especially with land-values and socioeconomic conditions, and as a result this indicates that La Ladera’s neighbouring area is socioeconomically more diverse than La Quintana, for example. In regards to the surrounding morphology, the analysis show that 40% of the buildings have one storey, 31% two storeys, 18% three storeys, 5% four storeys, and 6% is five or above storeys.

Figure 9 - (a) La Ladera’s NACH 2000, (b) La Ladera’s NAIN 2000, (c) La Ladera’s land use, (d) La Ladera’s socioeconomic strata, (e) La Ladera’s land value, (f) La Ladera’s building heights.
5. COMPARISON

In general, these results show that the three Library-Parks studied have reasonably good access to ‘through’ spaces (figure 10), both locally within the neighbourhood (travel usually covered by walking) and citywide connection (usually completed using the transport system of Metro, Metrocables and buses). However, the ‘to’ spaces surrounding each library is less consistent. At Guayabal, integration is reasonably higher due to its location within the formal urban grid and near to the city centre. By contrast, at La Ladera and La Quintana, integration is considerably lower, exposing the separation in the urban grid between formal (integrated) and informal (segregated).

With regards to public facilities, it is clear that these have a larger presence in both La Ladera and La Quintana, each presenting more than double the number of public facilities than Guayabal. In addition, La Ladera and La Quintana have large areas of land with low socioeconomic banding and land values. This could be an indication that the municipality is attempting to create a larger presence within the poorer communities. Finally, in regards to the building heights, the vast majority of these are between one and three storeys, indicating a common profile of urban density.

Figure 10 - Comparative results for Guayabal, La Quintana and La Ladera. (a) Surrounding public facilities in total number. (b) Surrounding land value.
6. DISCUSSION

This analysis investigated the urban distribution of the Library-Parks within Medellín and how they connect to the surrounding urban fabric. This opens up an opportunity to discuss how this distribution connects to the urban discourse related to Medellin’s upgrading programme.

Much of this early discourse related to ‘Social Urbanism’, which was initially ‘the main framework for all urban projects, especially those located in the deprived neighbourhoods of the city’ (Calderon 2012). This was supported by the discourse ‘of paying off the city’s historical debt to the long-abandoned poor sectors’ (Brand 2013). By simply examining the location of the libraries in relation to the socioeconomic map of Medellin, it is clear that the majority of these are positioned within the lowest socioeconomic bands, though a couple – namely, La Quintana and Belen – are in slightly higher bands. Another key element was the ‘architectural quality’ of these buildings for the poorest communities. The municipal administration spoke of ‘building better architecture, which the people can be proud of, which builds the community’s self-esteem and sense of belonging’ (Brand 2013). The Library-Parks clearly stand out in their scale, form, materials and colour, and announce state presence worthy of the wealthier sectors of the city. Hence, architecture became a key tool for not only creating high quality environments that citizens can value, but also for enforcing state presence. Yet, these buildings do not just provide state presence or create self esteem for the poorest neighbourhoods, they also provided a variety of social services such as computer and information technology, training courses, cultural activities, spaces for sport and recreation, social programmes, business set-up advice and so on. Therefore, it could be argued that the Library-Parks on their own address the three key fundamentals of the PUI program, “that whenever there was an urban intervention, in parallel to the physical transformation, there were new social/institutional programs and activities that complemented the physical change” (Echeverri and Orsini 2010).

Yet, whilst these libraries position within the backdrop of an informal settlement provide a striking image and representation of Medellin’s key transformation strategy, they do not reveal the full extent of the PUI program. This was more than just one building, ‘it involved shifting substantial public investment to the poorest sectors in the form of infrastructure, public buildings and services, and urban space and environmental improvements’ (Brand 2013). Therefore, whilst the Library-Parks symbolise Medellin’s transformation, it was equally important that they function within a series of other public facilities, to promote the idea of inclusion. Calderon (2008) explains that ‘the PUI’s main strategy is to concentrate in an integral and comprehensive approach all the actions of the municipality, converging resources, projects and programs in a delimited area’. He further mentions that these ‘projects and programs are located in strategic areas of the neighbourhoods and are considered as “magnets” and “detonator” of development in all the other fields’ (ibid.). Consequently, the urban grid surrounding each Library-Park is an extremely important factor, since it has the ability to connect people to these public facilities and achieve the objective of the PUI.

One of the best ways to connect local residents to public facilities, including the Library-Parks, is by positioning these facilities nearby local ‘through’ routes. Using the spatial measurement of NACH, it is clear that all the library-parks have positioned nearby local ‘through’ routes, providing good connections to and from the libraries. Yet it is not only at a local level that the Library-Parks are well connected to ‘through’ spaces. Most are not far from important ‘through’ spaces at larger urban scales, which provide connections to the city centre. This spatial positioning allows the Library-Parks to be easily accessible for the local residents, allowing natural movement to pass each library, or at least nearby. This was very important for the PUI, as the physical component of this ‘aims to improve and construct spaces where people can meet and build a greater sense of community and where the satisfaction of the collective needs such as recreation, culture, education and leisure can be met’ (Calderon 2008). We show that this was achieved by directly connecting the Library-Parks to important ‘through’ spaces at a local scale.

While strong ‘through’ space indicate good connections within each neighbourhood, frequently there is weak ‘to’ space surrounding each library. This is often a result of being located nearby two different urban systems – formal and informal. This is evident at both La Ladera and La...
Quintana, but not Guayabal. The result of which creates weak integration, especially above a very immediate local scale. Yet, whilst it is clear that the Library-Parks are not always positioned in areas of high integration, their location nearby formal neighbourhoods provides the opportunity for other communities to use their facilities. This was at the heart of much of Medellin’s urban upgrading program, as it aimed to break down barriers and integrate previously conflicting neighbourhoods. The PUI ‘aims at the improvement of the mobility, accessibility and connectivity between different neighbourhoods and the city’ (Calderon 2008), this had the ambition of creating connections between the poorest neighbourhoods and the rest of the city, making residents feel a part of Medellin as a whole. Elsewhere, this has been done using bridges, cable-cars and strategically positioned football pitches, yet this analysis suggests the facilities and open spaces of each Library-Park also provides this opportunity for inclusion.

Furthermore, the analysis indicates that the Library-Parks are easily accessible at a local scale. Yet, because of the often-contradictory urban form, they are not positioned at the centres of each community, but instead on the edge. Nevertheless, this could lead to a positive effect, since their position provides the opportunity to mix different communities, particularly by integrating segregated areas with the local centres of Medellin.

One of the most important elements of the PUI was the introduction of a wide network of public facilities to the poorest neighbourhoods. This aimed to provide a wide variety of opportunities to the poorest citizens in Medellin and improve the credibility and trust towards the municipal institutions. Calderon (2012) explains that “social and institutional programs and activities aiming at education, culture, sports and recreation and employment reinforced and made active use of the new public spaces and public facilities”. Among the key cases studied in this paper, we saw that La Ladera has 95 nearby public facilities, La Quintana has 93, and Guayabal has 43. These include facilities for education, sports, community, faith, public services, culture, etc. As has been previously discussed, the areas surrounding La Ladera and La Quintana are deemed significantly less prosperous than Guayabal, hence it is understandable that more public facilities are positioned here, since this was a direct aim of the PUI to target the poorest neighbourhoods. With this the municipality now has a larger presence in these communities, where previously this was not the case. This demonstrates that Medellin’s upgrading programme is more extensive than just the captivating architecture of the Library-Parks. Rather, it attempts to introduce a network of public facilities to some of the poorest communities and knits them together with the existing urban grid. This provides spatial coherence to the upgrading projects. At the same time, however, the spatial distribution of Library-Parks and other public facilities provide an entrance for public institutions and state authority, which gradually impose themselves in informal sectors. As Brand explains (2013), the upgrading process has “lead to the formalisation of things such as electricity and water connections, the legalisation of property holdings and imposition of property taxes, permissions and controls over social events, the inclusion in official business registers, and so on”. In short, implicit in the Project of Urban Upgrading is the idea that a formal economy controlled by the state constitutes an ‘upgraded’ version of a culture characterised by informal economy, incremental growth and self-management.

Whilst Medellin’s upgrading programme is often symbolised by its iconic statements, such as the Library-Parks or the Metrocables, which help support the discourse of ‘social urbanism’ and the ‘Medellin model’, the actual upgrading program is much wider reaching, often going beyond spatial and physical forms by including major – and often debatable –institutional and social changes. Yet, its real strength may have actually been its understanding of the existing urban grid and its abilities to position key interventions in pivotal locations, which could then connect to other public facilities to form a spatially cohesive transformation.

7. CONCLUSION

Most of what is published about Medellin’s urban development relies on ‘slogans’ and ‘metaphors’ and these often glorify its ‘rags to riches’ story, using the image of violence and narcotics to capture people’s attentions. However, behind all of this rhetoric, there has been the transformation of many of its poorest neighbourhoods. The Library-Parks stand at the
hearts of this transformation and this paper has shown how the existing urban fabric contributes to their success. Firstly, the paper characterises each building based on their spatial location within their neighbourhoods. Secondly, and more importantly, the paper discusses how these characteristics relate to Medellin's upgrading discourse. In particular, we show how the PUI's objectives are materialised in space, highlighting how it works as a framework in which to physically, socially and institutionally transform existing neighbourhoods in Medellín. Further work can then be done on how the urban conditions we described impact on these facilities' everyday use by the population, shedding light on the question of how public architecture promotes social change, and discussing the ways in which state power is made manifest in informal settlements. In particular, we may now analyse the interrelation between its wider programme, its interior spatial structure, its location within the urban fabric and the symbolic messages it carries.
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TO GO WITH THE FLOWS OR TO FLOW WITH THE NODES?
An exploration of ‘post-disciplinary’ theories of movement in space syntax and mobilities research

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ABSTRACT
All too often the dialogue between space syntax and the social sciences pits space against society. For this reason the recent ‘mobilities’ turn in urban studies – stimulated by John Urry’s key (2007) text *Mobilities* – presents space syntax research with an opportunity but also a theoretical challenge. Urry’s ‘mobilities paradigm’ advocates a broad ‘post-disciplinary’ convergence on infrastructural systems as agents actively creating and restraining social competences through the effects they have on movement and communication. Space syntax theory and research is well placed to make a substantial contribution to this emerging field. For example, the theories of ‘natural movement’ and ‘movement economy’ offer a radical conceptualization of quotidian pedestrian and vehicular movement-space that, in comparison with other forms of transport and communications infrastructure, are seriously under-conceptualized by Urry. For space syntax theory, on the other hand, the mobilities emphasis on the infrastructure of movement-space as enabling social practices to emerge in particular historical, geographical and cultural contexts invites consideration on the extent to which the implicit normativity of the space syntax theory of urban movement has been repressed in the name of prioritizing the objectivity of its contribution to the design process, over the benefits of wider interdisciplinary – or indeed ‘post-disciplinary’ engagements.

KEYWORDS
Space syntax theory, John Urry, mobilities, movement, interdisciplinarity

1. INTRODUCTION: MOBILITIES AND MOVEMENT-SPACE
In his landmark synthesis *Mobilities*, John Urry (2007) boldly introduces mobilities as a “new paradigm” in social research (p.46) – declaring his aim as nothing short of “establishing a movement-driven social science” (p.18). Since then the field has expanded rapidly with a dedicated academic journal *Mobilities* (Taylor and Francis, 2011) and numerous publications and conferences using mobilities as an organizing theme. Indeed the 10th International Space Syntax Symposium included a series of papers on ‘Urban studies, transport and mobility’, although interestingly Urry’s work was not referenced in any of these studies¹. Even so, the apparent congruence of aspects of mobilities studies² and a substantial body of theory and research in space syntax around the theme of corporeal movement deserves a more sustained examination than it has hitherto received. Of course, therein lies the interdisciplinary rub – the acknowledgement of which must precede the realization of Urry’s aspiration for mobilities as a ‘post-disciplinary’ research domain. On the face of it at least, *Mobilities* derives from a tradition

¹ http://www.sss0.bartlett.ucl.ac.uk/category/04-urban-studies-transport-and-mobility/ [accessed, 4.2.17]
² http://www.lancaster.ac.uk/cemore/mobilities-journal/ [accessed, 4.2.17]
of research in human geography, heavily influenced by Lefebvre, which Hillier (2008) has referred to as the 'spatiality paradigm' that puts 'society first', in the sense of producing social space in the image of dominant socio-economic forces. On the other side of this argument is the theory and formal analytical methods of space syntax, that put 'space first', in the sense of asserting the productive role of society's material organization in generating and constraining social relations. This paper does not claim nor advocate any synthesis, but makes the case for further interdisciplinary engagement on the basis that a broad focus on the conceptualization what Thrift (2011) nicely characterizes as 'movement-space' promises a way out of the 'space first', 'society first' binary. This does little to develop the space syntax theory of the encounter field in the context of widespread scholarly interest in how increasingly global infrastructural systems are transforming social practice and the power they bestow on the political and corporate regimes that produce and maintain them (Easterling 2014).

Interdisciplinary engagement cuts both ways. Space syntax theory is well positioned to address a clear weakness in Urry’s ‘mobilities paradigm’ — namely its inadequate conceptualization and formal articulation of the quotidian mobilities of inhabited space – while acknowledging that these too comprise a normative ‘infrastructure’ of movement in different cultural and historical contexts — including, it will be argued, our own. Urry quotes approvingly Castells’ (1996) pronouncement that networks “constitute the new social morphology of our societies”, pre-eminent over social action (quoted in Urry 2007, p.212). Yet from a space syntax perspective one is entitled to respond with Hillier’s (1989, p.6) argument that asserts spatial configuration as an “intrinsic” aspect of social morphology. Hillier maintains that ‘networks’, both material (‘spatial’) and virtual (‘transpatial’) are the fundamental synchronizing elements of social ontology. This implication is that this is as true of ‘simple’ and historical societies that are the specialist focus of anthropologists and archaeologists, as it is of the settlements of an emerging global society powered by digital communications technology that are the principal focus for mobilities studies. From Hillier’s perspective, while there is clearly a need to shift the scale of analysis, there is no need to shift social ontologies to acknowledge the transformations of contemporary globalization. Yet for Urry as for Castells the plurality of interlinked networks for travel, communication and economic transitions that characterize the ‘space of flows’ does indeed herald a new research paradigm (i.e. Mobilities) in which the material spaces of everyday life in the public realm have increasingly little purchase on many areas of social practice. In that sense their work decentres the ontological primacy of the material organization of inhabited space asserted by Hillier and Hanson as the foundational pre-requisite of becoming a social human. Is this simply a question of finding the right, or does it raise more fundamental theoretical issues about the relationship of the material and corporeal with the immaterial and disembodied?

2. CONCEPTS OF MOVEMENT IN SPACE SYNTAX AND MOBILITIES STUDIES

Urry notes how the expansion of systems of mobilities has remained something of a ‘black box’ for the social sciences (meaning, I suspect, a place where formal descriptions of different networked infrastructure systems are called for!). Embracing both complexity science and the ‘post-humanist’ turn associated with Actor Network and Assemblage perspectives, Urry’s Mobilities is as concerned with non-human as it is with human agency (Bender, 2010; De Landa 2006). Urry (2007, p.47) posits five kinds of mobility: corporeal, material objects, imaginative, virtual and communicative. The main focus is to explore the agency of technological infrastructure conceived as socially generative systems, enabling new kinds of socio-spatial practices to emerge. Urry’s starting point philosophically is that neatly objectivist (i.e. that tend to the technologically reductionist) and subjectivist (i.e. unable to address the nature of human agents’ reliance on material systems that enable mobility) approaches provide an inadequate epistemological basis for his new paradigm (p.50). There are clear parallels here with how Hillier and Leaman (1973, p.508) exposed contemporary theorizations of the relationship between space and society as an alliance of ‘mutually exclusive’ epistemologies.

Urry then, broadly shares with Hillier an awareness that society is inadequately theorized in purely interactionist terms, i.e. as individual social interactions projected onto an intrinsically asocial environmental backdrop (where an interaction is not taking place). Both mobilities and
space syntax highlight the relation of the individual to enabling material-technological systems that extend beyond any individual body yet are fundamentally implicated in the creation of the totality we recognize as society. Urry puts it this way:

social science mostly focuses upon the patterns in which human subjects directly interact together and ignores the underlying physical or material infrastructures that orchestrate and underline such economic, political and social patterns. (Urry, 2007, p.19)

Hillier and Hanson (1984, p. 45) establish in the *Social Logic of Space* that what they refer to in terms of embodied social action is the essential performative dynamic that connects a society's materialization in space to its reproduction in time. As early as the preface Hillier and Hanson claim:

By giving shape and form to our material world, architecture structures the system of space in which we live and move. In that it does so, it has a direct relation - rather than a merely symbolic one - to social life, since it provides the material preconditions for the patterns of movement, encounter and avoidance3 which are the material realisation - as well as sometimes the generator – of social relations. In this sense, architecture pervades our everyday experience far more than a preoccupation with its visual properties would suggest. (p. ix)

The points of congruence in these passages also highlight some divergence in how the respective research paradigms are developed. There is something of an irony in the fact that Urry's macro-sociological concern with socio-economic and political patterns disguises the emphasis he places on the close sociological analysis of the social practices of mobility he uses to get there. On the other hand Hillier and Hanson’s theoretical emphasis on the performative nature of patterns of movement, encounter and avoidance in the *Social Logic of Space* disguises the lack of development of a theory of embodied social practice that could facilitate syntactical conceptualization of spatial cultures at the micro scale where social groups are differentiated, preferring instead to concentrate on achieving a macro-level synthesis (Liebst, 2012).

In deploying the agency of non-human actors Urry suggests some interesting possibilities for a space syntax theory of the social practice, especially when one considers the materialization of a given spatial configuration as a non-human actant itself. This might be conceptualized as some sense as an emergent ‘infrastructure’ of social practice no less (in fact much more) than, for example, a railway network. The plurality of networked infrastructure that constitute a movement-space of material, communicative and symbolic possibilities for social practice – recalls the heterogeneous possibilities of Hillier and Leaman’s ‘logical space’:

... an imaginary, many dimensional space created by and filled with systems of signs, symbols and representations. It exists neither purely in our heads, nor in real [i.e. physical] space outside, but constitutes the medium through which the relation between the two is made (Hillier and Leaman, 1973, p.501).

Many kinds of networked agencies might be assumed to constitute ‘logical space’ and realize the particular built-environment materialities of the world in which live. For Urry the idea of the *hybridity* of human and non-human agents, taken from the actor-network tradition is important in suggesting how bodily practices become reconfigured through their use of technological systems of mobilities and communications that both extend and fragment their presence in geographical and virtual space. In this sense we might understand spatial configuration as a kind of *assembling agency* through which bodies becomes social as they participate in the plurality of corporeal, material and informational networks they inhabit (cf. Netto, 2016). Hillier himself uses the term ‘hybridity’ to suggest a parallel between ties that link locally dense to globally diffuse regions of social networks and the local to global structures linking the ‘background’ and ‘foreground’ networks of cities (Hillier, 2016).

Both Urry and Hillier emphasize the association of access to mobilities infrastructure and social privilege. For Urry (2007, p.194-7, 39), ‘network’ or ‘motility’ capital provides access to social networks that perpetuate economic and cultural capital and define a new globalizing social stratum of highly connected individuals. He argues ‘network capital points to the real and potential social relations that mobilities afford’ (p.196). This dynamic is disruptive of traditional sociological categories of class and party-political allegiance which become increasingly defined by access to networks rather than place-based affiliations. Given that much of what Urry is describing takes place in the context of a rapidly urbanizing world, one wonders whether there is scope in this theorization to engage with Hillier’s formal articulation of cities as fundamentally social network building entities; spatial-agglomerative processes that generate non-local relations (Hillier 2010). In this context there is broad agreement between Urry and Hillier that an undue focus on the qualities of locality and ‘place’ elides what is really at issue, i.e. how non-local network relations are a socially structuring agency.

When, however, Urry states, again paraphrasing Castells, in the context of a discussion of air travel that “geographic proximity in most countries no longer shapes social relationships” (Urry 2007, p.135), it is hard to not to think that he is perpetuating the what Hillier and Netto (2002, p.183) refer to as the “myth of historic spatiality” – that is the idea that as societies ‘progress’ technologically they move from comprising homogeneous territorial communities to aspatial networks. Yet, as has previously been pointed out, such an argument lacks credibility in the face of Hillier’s assertion that all societies combine spatial (material) practices with aspatial (semantic or institutional) identities. For Hillier being social is fundamentally a process of overcoming the space that constrains non-local networks (Hillier and Hanson, 1984, p.236). Clearly, the digital frontier has opened up the global frontier but this means less that the materiality of spatial practices cease to matter, simply that they increasingly have the potential to propagate social relationships over a greater extended area of geographical space.

A certain presentism is certainly evident in Urry’s *Mobilities*. While he is strong on articulating the socially transformative effects and *affects* of systems that enable non-pedestrian movement by rail, road, air and sea, and mobile communication via a range of electronic devices – he is weaker on conceptualizing the movement and encounter field of inhabited space which is so central to space syntax research. Despite his acknowledgement that ‘all movement involves intermittent walking. Pedestrianism is everywhere...” (Urry, 2007, p.63) and that walking is an aspect of ‘multiple socialities’ (p. 90) there is a strong if implicit technologically-directed historical narrative at work in which ‘pedestrianism’ is increasingly superseded by other forms of mechanized and digitized motility and communication. I suspect that this is less because Urry particularly believes this to be the case but rather because he lacks the theorization to articulate what he categorizes as ‘pavements and paths’ as mobilities infrastructure in a manner parallel to the kind of system represented by railway lines and airport connections. By contrast Hillier and Hanson (1984) provides a way of thinking about and researching how society’s material organizes arises from the generic imperative to cross space to encounter ‘the other’ – a contribution that directs attention towards, but is explicitly not restricted to, spatial encounters.

There is nothing equivalent in Urry’s *Mobilities* and this leads to difficulties. The social practices enabled, for example by aviation and communication networks cannot be entirely abstracted from corporeal movement dynamics in material space any more than their social affect can be comprehensively explained in these terms. Urry’s interesting account of motorized automobility as a non-linear, self-organizing system, for instance, is rather impeded by not considering how contemporary road systems largely emerged from historical networks that long pre-dated the automobile era (Urry, 2007, p.118; Dhanani, 2016).

The space syntax theory of movement offers a much richer set of concepts than mobilities for thinking about how the spatial configuration of movement-space shapes the material world in which other material infrastructure are, to an extent, embedded and practiced. At the same time there is also a sense in which the role of movement has not been fully resolved in space syntax theory. It was not until the completion of the computationally-enabled phase of research that concluded with the publication in 1996 of Hillier’s *Space is the Machine* that movement-
space really moved to the centre stage in the theory and practice of space syntax. Drawing on a body of research conducted by the international space syntax research community, Hillier (1996) assimilated two new components on the built environment into space syntax theory – the theories of ‘natural movement’ and ‘movement economy’. In the theory of natural movement Hillier proposes that the spatial configuration of the plan or urban grid itself produces ‘attraction inequalities’ that privilege some spaces over others for movement on a probabilistic basis, prior to any consideration of ‘attractors’ on the basis of design aesthetics or land-uses (Hillier et al 1993). The theory of the movement economy complements this approach by proposing that land-uses benefitting from a high rate of movement will tend to cluster in more accessible networks locations at a premium cost, while other land-uses situate themselves in relatively less integrated positions in the network, depending on the economic value they assign to accessibility. By launching an evidence-based assault on the attractor-based origin-destination models commonplace in urban planning Hillier and his colleagues demonstrated that space matters, not in naïve terms, for example representing community as a function of locality or spatial determinism, but as a generative socio-spatial dynamic through which social life emerges.

Griffiths (2011) proposes that while Hillier conceives cities (and by extension social systems) as systems of organized complexity, movement in space syntax theory is largely confined to a Newtonian model, regarded as a constant that simply ‘just happens’ all things being equal (Hillier 1996, p. 393). Movement in this sense is that which does not need to be explained – hence the critique it presents to origin-destination thinking. The difficulty is that explaining movement as the probabilistic outcome of the laws of spatial configuration means that it really has very little to say about the specificity and plurality of movements across history, cultures and between different social groups. Quite deliberately, moving bodies are conceptualized as kind of proxy to demonstrate probabilistic configurational structures, rather than as agents of a complex socio-spatial process. It is telling how small-scale urban movements (i.e. within a given convex area) hold relatively little theoretical interest for Hillier in comparison with larger-scale movements that link across spaces, a point he emphasizes by differentiating local movements as ‘occupation’ (Hillier 1996, p. 316-7). Yet such an argument tends to privilege the synchronic social totality over ‘messy’ diachronic processes where no privileged scale of analysis can be assumed.

Acknowledging this critique however, highlights the unresolved tension in space syntax theory which resides in its rather unique but also Janus-faced status in aspiring to be both a theory and method for application in contemporary architectural and urban design practice, and a social theory of space and method for built environment research which seeks broad engagement with the theoretical literature of Lefebvre and Soja, among many others as Hillier (2008) exemplifies. The tension arises from the fact that the ‘configurational’ approach to design (for want of a better expression) cut its teeth in a particular historical context and largely in response to a particular historical problem (the perceived failure of modernist social housing and urban design in post war Britain) that lends a clear ideological inflection (the futility of social engineering) to the de facto normative practice of seeking to ‘improve’ the quality of life in the urban realm through architectural design. The overarching social theory, however, (as presented in Hillier and Hanson, 1984) aspires to develop a conceptualization that can put built environment research on an evidence-based footing. This claim of space syntax research to scientific objectivity was pushed hard in the work drawing on the natural movement and movement economy theories that flowed from Space is the Machine, providing strong vindication of Hillier and colleagues’ belief that, after modernism, architects needed to understand theoretically how space actually works to produce social outcomes – when their designs were failing to produce the ones they had expected. I would argue that this normative imperative of space syntax implemented design practice had the unintended effect of obscuring theoretical reflection on the normative positioning of the associated but distinct identity of space syntax as a social theory of space. Its theoretical preference for the generic description of social totalities on a comparative basis has impeded elucidation of the pluralities and ambiguities of movement and encounter evident at the micro-scale, where further conceptualization of spatial configuration as an emergent (and historically contingent) field of social practice – perhaps a materialized ‘spatial infrastructure’ in
a sense recognizable to mobilities research (and ‘mobilities design’ – see Jensen 2016) – would be beneficial (Liebst, 2011, 2016; Netto, 2016). In seeking to explain its particular trajectory of theoretical development, the next section of this paper seeks to locate the normative identity of space syntax as a social theory of space broadly in a utilitarian tradition of thinking on urban planning reform traceable back to a physiological strain of natural theology in the late eighteenth-century

3. MOVEMENT AS IMPROVEMENT: SANITARY ECONOMY AND MOVEMENT ECONOMY

The historian of ideas, John Pocock (1993, p.311), has used the term ‘sattelzeit’, literally a ‘time in the saddle’, to describe what he saw as a shift in dominant discourses in early nineteenth-century Britain. Very approximately, mid-eighteenth-century discourses associated with civic virtue seemed to be eclipsed by discourses of utility and commerce in the early nineteenth-century (cf. Hunt 2004). The prevailing counter-revolutionary ideology of Burke did not provide the basis for a sociological critique of modernity as the Revolution precipitated in France had done. Instead, it was in Britain that the ostensibly apolitical social survey was pioneered, a development that was closely associated with the industrializing cities. One aspect of the sattelzeit was the gradual adaptation of Paley’s theory of Natural Theology (a benign God who could be discovered in an ordered universe) into a proto-functionalist social theory which also co-opted the traditional organic analogy of the city and the human body. The city became a legitimate area for systematic enquiry aimed at finding out how it fitted into God’s rational and benevolent universe. Robert Vaughan’s Age of Great Cities (1843) is written in this tradition, and he is one of the relatively few thinkers of this time who saw urbanization in an unambiguously positive light: confident that, in time, the knowledge cities emanated would produce solutions to the problems they produced. How else would a beneficent deity arrange things?

Urbanists especially have tended to conflate the physical expansion of the nineteenth-century city with environmental considerations in a tradition that has its origins in the analogy of society as a biological organism. Graeme Davison (1983) has shown how the early social analysis of towns was often conducted by doctors who, in the light of physiological discoveries concerning disease, circulation and homeostasis, developed the organic metaphor into an anatomical diagnosis of urban maladies. Doctor Thomas Southwood Smith, a pioneer of sanitary reform argued that the city, like the body, functioned as a ‘sanitary economy’, a system, where the free circulation of water and air and removal of waste from the urban system created the conditions for a healthy life the city just as it prevented disease in the body. The sanitary reformers offered a greatly improved diagnosis of urban conditions in recognizing the connection between systemic factors (the circulation of clean water, for example) and localized problems. The previous science of ‘medical topography’, which it replaced, based its diagnosis on the ‘qualities’ present in local conditions. By contrast, in his 1827 treatise The Use of the Dead to the Living, Southwood Smith argued that:

Disease is denoted by disordered function; disordered function cannot be understood without a knowledge of structure; structure cannot be understood unless it is examined.

(quoted in Davison, 1983, p.361)

The difficulty with the anatomical analogy is, quite simply, that a body is not the same thing as a city, no matter how well it can be understood metaphorically in those terms. In the Victorian period the utilitarian sanitary economy became conflated with a ‘moral economy’ where poor physical environments and the presence of vice became inextricably associated; what Evans (1997) characterized as the contagious nature of immorality within the nether world of London’s rookeries. The desire to replace these labyrinthine slums with thoroughfares was certainly informed by the Victorian association of urban morality with circulation, ‘the street was not a place to loiter, but to move on’, as Daunton (2000, p.6) puts it. Once it is conceded that there is an association between environmental degradation and social vice it is a short step to find social vice where there are signs of environmental degradation – particularly dirt. Accessibility then, ‘through movement’, was viewed as ‘good’ in normative terms by middle
class urban elites, a way of cleaning up the city and making it more governable and even less revolutionary (Hobsbawm, 1969).

Without suggesting that such a physiological conceptualization of movement governs the theory of spatial configuration (quite clearly it does not) there is no doubt that much applied work in the field aims, quite properly, at establishing rational channels of movement between historical centres and more recently developed areas of cities, undermining spatial patterns of social segregation and creating high-quality public spaces where different social groups may easily mix. From this perspective one can identity in space syntax urban design practice, an implicit advocacy of what Bookchin (1974) refers to as the ‘bourgeois city’ (see also Griffiths 2015). In the European tradition these were more or less self-governing communities built through wealth in trade and which, in the second half of the twentieth century, were so often said to be in crisis from war damage, the consequences of modernist redevelopment and poor, socially divisive, systems of regulation and governance. It is in such ‘cities of production’, the arrangements of their streets and squares that space syntax as an applied theory of urban design has achieved so much. Yet historically such interventions have much in common with the eighteenth and nineteenth century sequences of urban improvements most clearly associated with Victorian ‘civic pride’ - arguably revived in the late twentieth-century by the ‘urban renaissance’ strategy of the Blair government - that sought to make the industrial city endurable for its middle-class inhabitants. While this class did not usually possess as individuals the financial resources or alternative residencies available to aristocrats, collectively they stood to benefit most from implementing urban reforms that could improve the quality of urban living and ameliorate the worst environmental conditions of the slums, which they feared as a potential source of social revolution. Urry (2007, p.91) himself comments on the new public spaces of the nineteenth-century city in characterizing the nineteenth-century as an epoch of ‘public mobilization’ through a massive expansion in public mobilities infrastructure, a similar point is made by Sennett (2002, p.317-354). In other words, one can associate a focus on urban-scale circulation with a particular phase of urban reform from the late-eighteenth-century and it is this, strongly normative vision of the bourgeois public realm that, I would argue, currently characterizes the space syntax theory of movement-space. The point is not to criticize space syntax as an urban design theory for this emphasis but simply to insist on movement as a normative category – that is as something that is not generic or socially unambiguous, especially when approached not at the macro-scale of social totalities but at the micro-scale where distinctive spatial cultures emerge and what might be considered to be ‘natural’ in culture is most likely to be contested.

Hillier has condemned modernism as essentially anti-urban. He has traced this influence back to the early town planners, particularly the Garden City movement, which was, he argues, based on an ironically atavistic response to the environmental and social squalor of the nineteenth-century industrial city that led to a distaste for the very idea of cities. Trevelyan’s bestselling English Social History (in print continually since its publication in 1942) is indicative of the way in which contemporary cities became viewed in wider culture at this time.

When Waterloo was fought, rural England was still in its unspoilt beauty, and most English towns were either handsome or picturesque. The factory regions were a small part of the whole, but unluckily they were the model for the future. (Trevelyan, 1986, p.477)

In Hillier’s view post-war urban theorists such as Lewis Mumford have much to answer for in translating their belief in what Mumford (1961, p.515) called the “de-natured” industrial city into an anti-urban planning ideology –still evident in writers such as Hunt (2004, p.16, 321). For Hillier, such anti-urbanism gave succour for modernism’s undermining of the line (or street) as the fundamental (natural) organizing principle of cities, in the name of social engineering based on left wing and rural utopianism. Such responses to insanitary urban conditions he argues:

...do not derive from an understanding of cities. On the contrary, they threaten the natural functioning and sustainability of the city. (Hillier, 1996, p.136)

Yet Hillier’s, no less than Mumford’s, recourse to a vocabulary of what is or is not ‘normal’ or ‘natural’ is indicative of a largely unarticulated ideological position in which light-touch interventions to restore ‘natural function’ are preferred to the utopia-building schemes of...
the modernist planners. In that sense one can identify a clear lineage between theories of the city conceived as a natural system in the spirit of the early medical investigators and Hillier’s own articulation of urban function. For example, space syntax research has argued how poor implementation of movement-circulation design is capable of causing social malaise where the interface between different age groups is minimized (Hillier 1996, p.183-214). There is a distinct echo here of early nineteenth-century physiologically-inspired urban sociology with its association of good circulation and the moral (or at least ‘healthy’) urban environment.

In fact the whole principle of design ‘intervention’ has strong medicalist- functionalist connotations, implying an intention to restore the proper or ‘normal’ functioning of the system. Yet whereas a medical patient can clearly decide the extent to which he or she feels ill, and indeed a large de facto consensus may exist about the definition of a contemporary problem in urban design, when it comes to applying key space syntax concepts of movement-space to an interdisciplinary range of enquiries from historical archaeology to contemporary urban anthropology – the question ‘how do settlements function to produce social solidarities?’ may be too abstract to help identify and describe the diverse aspects of a spatial culture as these emerge at relatively small scales of socio-spatial practice in particular times and places. Urry (following Sennett) reminds us that representations of networked movement and circulation can become fetishized in a society in which social status is associated with mobility (Urry, 2007, p.207).

4. CONCLUSION: MOVEMENT AS NORMATIVE

It is relevant in this context to consider how Urry prefers to ground the Mobilities paradigm in Georg Simmel’s concern with modes of human association and circulation systems, over the Durkheimian emphasis on social solidarity, which appealed to Hillier and Hanson in The Social Logic of Space (1984). Although heavily influenced by Durkheim, Simmel’s focus on mobilities serves to insulate his work from the conflation of social morphology with social physiology that precipitated the crudely functionalist approach of modernist sociology with its overriding concern for maintaining the stability of the social organism (Andrews, 1993, p.122-3). Yet the theorization of ‘movement-space’ in space syntax is, I would argue, neither functionalist nor positivistically modernist as an analytical proposition, but rather utilitarian in an ethical-normative sense. As an approach to urban design it seeks to maximize the public good (for example by contributing to the creation of high quality mixed-use public spaces) while theoretically it struggles to grapple critically with interdisciplinary questions such as gentrification, which, while neatly demonstrating the theory of the movement economy, equally indicate how it is usually social elites who are most at liberty to appropriate what Marcus (2010) has called the ‘spatial capital’ of the public realm, as much as they accumulate Urry’s ‘network capital’4. Further reflection on its own normative-ethical positioning as an analytical approach to design could help liberate space syntax theory more generally from the functionalist echoes of its intellectual antecedents and lead to a development of those components of the theory concerned with mobilities and encounter through interdisciplinary engagement with research questions beyond those typically raised in contemporary urban design and planning scenarios, while also offering fresh critical perspectives on these.

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THE IMPACT OF URBAN TRANSFORMATIONS ON THE MORPHOLOGY OF STREETS NETWORKS.
A study on Paris between 1300 and 1871

ABSTRACT
This research takes place in the field of quantitative analysis of historical streets networks. During the last decades, many studies have used network analysis or space syntax approach in a diachronic perspective, either to observe the interdependence between network configurations and land-use, or to explore the link between network configurations and known urban phenomena, such as densification, dispersal or expansion. These researches often focus on one single transformation rather than on the long time evolution of networks. In this work, we will explore the evolution of the street network of Paris, between 1300 and 1871, and link this evolution to all the transformations that occurred in the city during this period. The general question we are trying to address is what is the impact of urban transformations on the form (the morphology) of streets networks?

Our methodology is the following; we first describe the history of the city, by focusing on moments that have had an impact of the form of its street network. We then analyse this form, using graph theory, and compare it through time, so as to identify change and permanence. We finally face the evolution this form with the transformations in the city.

Our results revealed that the street network of Paris was subject to two kinds of interventions: spontaneous ones, which usually led to its expansion and densification, and planned ones, which led to its restructuration. We showed that the form of the network was thus differently impacted by these two kinds of processes.

KEYWORDS
Network Morphogenesis, Urban History, Graph Theory.

1. INTRODUCTION
Roads are necessary to reach a human establishment and enable its development, but they are in turn deeply impacted by this development. For instance, the emergence of a market in a certain establishment may redraw the road network, since most roads will probably converge to it (Caniggia, 1994; Dicks, 1972; Douady, 2016). In the same vein, streets are, at a local level, strongly impacted by social, cultural, economical or political transformations. Indeed, many studies revealed the impact of transformations in a city on the form of its street network, namely the length of roads, their width, direction, position in relation to one another, etc.
These researches spread recently because of the increasing use of quantitative tools in social sciences. Indeed, architects, urban planners and geographers mix their knowledge about cities with quantitative analyses, with the aim of describing the evolution of networks’ form in regard with various transformations in a city.

For instance, authors have tried to explore the link between transformations in land-use and the evolution of networks, either using modelling (Achibet, Balev, Dutot, & Olivier, 2014), or space syntax approach (Griffiths et al., 2013; Psarra, Kickert, & Pluviano, 2013; Vaughan, Dhanani, & Griffiths, 2013).

Other authors focused on the impact of a particular transformation in the city—such as expansion (Strano, Nicosia, Latora, Porta, & Barthélemy, 2012), densification (Barthelemy, Bordin, Berestycki, & Gribaudi, 2013), or dispersal and spreading (Gudmundsson & Mohajeri, 2013)—on the form of the street network. For instance, Barthelemy and colleagues (ibid) revealed, using graph theory, that the densification of Paris between 1789 and 1836 led to an increase in the number of intersections and the length of streets. For their part, Strano and colleagues (ibid) revealed that the expansion of Groane (in Milan) between 1833 and 2007 provoked an expansion and reinforcement of pre-existing structures in the network.

Our work represents a continuation of the latter, since we use quantitative tools so as to identify the impact of various transformations in a city on the form of its streets network. We will take as case study the city of Paris, compare its street network between 1300, 1652, 1790 and 1871, and put its evolution in relationship with the urban transformations occurring during this period of time, so as to reveal their impact.

These four dates will allow us to explore the impact of many kinds of transformations. Indeed, Paris grows a lot between 1300 and 1871 (see figure 1), and passed through periods of “self-organisation” as well as periods of “top-down planning” (notably during the Haussmann period).

![Figure 1 - The four graphs of Paris’ street network. Top left: 1300; top right: 1652; bottom left: 1790; bottom right: 1871.](image)
More generally, the results of this research will allow us to put forward hypotheses about the way a certain urban transformation impacts streets networks in general. Indeed, this will be a big step forward in answering the question: is the impact of a certain transformation – such as urban sprawl – on the network of Paris similar to its impact on other networks? If we compare our results to the ones obtained on other cities, will they be the same? Can we bring out generic conclusions about the way this or that urban transformation impacts streets networks in general? These questions will be addressed in further researches.

Our work requires many precautions. We first have to define precisely what urban transformations are we talking about. It is important to notice that urban transformations do not systematically have an impact on the network, partly because of the resistance of streets networks to “change” and their ability to adapt to various urban contexts. Considering that, it would be more appropriate to focus on urban transformations that have actually had an impact on the network. That is what Hanson did in her thesis (Hanson, 1989), since she explored the link between “morphological history” i.e. the evolution of the street plan (namely the form of the network), and “event history”, which refers to myriad localised interventions in the network, such as road widening or encroachments (Vaughan, 2015). Thus, when she studied the history of the city of London since the Roman period, she focused on “events” that have actually had a demonstrable effect on the network. She then put this “history of events” in relationship with the formal analysis of the street network (Vaughan, ibid), so as to explore the link between “morphological history” and “event history”.

Based on this approach, we will focus in the history of Paris on moments that have actually provoked interventions on the street network of the city. Besides, by focusing on interventions rather than transformations in general, we will be able to overcome the temporal lag between a transformation in the city (a new need, problem, …) and its actual effect on the network. Hanson’s work also helps us conceptualising our approach, since she treated separately the “morphological history” of the network and its “event history”. Caniggia and his colleagues (2000) help us going further in the definition of the “event history”, namely the history of “interventions” on the street network. According to them, the urban form – and thus the street network’s form, is subject to two kinds of interventions: the spontaneous (self-organised) ones and the planned ones. The former comes from little modifications made locally in the network, without “top-down” decision. These interventions are made according to the socio-economic forces and the urban practices of each context, so as to address punctual issues (carving out a road to build new houses, parcel out an agricultural land…). We can put in this category unplanned expansion and densification of the network.

For their part, planned interventions are usually more significant. They are decided by urban planners, public authorities, etc., usually to address a particular problem in the city, a new need, or to adapt the road network to a new context that transcends the city¹. For instance, when a city sprawls, the centre becomes too far and urban planners may be asked to restructure the street network, so as to ease the traffic. Later, when a second centre emerges in the city, they may be asked again to carve out roads so as to connect the two centres. We can put in this category of interventions planning operations such as Haussmann’s one in Paris.

These two kinds of interventions have different paces; the spontaneous ones are almost continuous in time while the planned ones are rather punctual. It means that these interventions can be concurrent: while public authorities plan something in the network, spontaneous interventions are still occurring, in agreement or not with the planned one. Hence, planned interventions often speed, halt, reorient or reverse completely the spontaneous evolution of the road network.

In the light of the above, we decided to refine our general question: what is the impact of each one of these interventions on the street network? Is it possible, based on the form of the street network, to distinguish moments of spontaneous interventions, and moments of planned ones? Put it another way, is the “morphological history” of the street network

¹ Such as a War.
of Paris different during moments of spontaneous interventions than during moments of planned ones?

To answer the questions above, we chose to treat separately the two kinds of “histories” mentioned by Hanson. Indeed, we will first focus (on section 2) on the “event history” of the street network of Paris between 1300 and 1871, and distinguish, in this history, moments of spontaneous interventions and moments of planned ones. After that, we will explore the “morphological history” of the network during this period (section 3). Thereafter, we will put these two histories in relationship, and try to put forward hypotheses about the impact of each intervention on the form of the street network (section 4). We will finally verify if each kind of intervention—the spontaneous and the planned ones—has had a specific impact on the street network of Paris.

2. THE “EVENT HISTORY” OF PARIS’ STREET NETWORK

Here we will try to highlight the urban transformations through which Paris passes during the four studied years, by focusing on the interventions made on its street network. The purpose is therefore to answer the question: what happened in the street network of Paris between 1300 and 1652, 1652 and 1790, 1790 and 1871?

Note that this “event history” of Paris’ street network is based on researches made by historians, archaeologists and architects (Bove, 2012, Gherdevich & Noizet, 2014; Huard, ND; Salat, 2011).

2.1 PARIS BETWEEN 1300 AND 1652:

In 1300, Paris was conserving some ancient parts such as the « Cardo maximus » of Gallo-Roman Lutetia (rue Saint-Martin to the north, rue Saint-Jacques to the south). More recent townhouses such as Les Halles (Huard, N.D) also existed at that time. These townhouses were composed of lots, organised either around impasses, or as a little city in the city. Spontaneous urbanisation was often taking place nearby these townhouses, all along the rural ways.

Thus, between 1300 and 1652, Paris was expanding, absorbing the Charles V’s enclosure and reaching the Louis XIII’s one at the end of the 16th century. During this period, ways—except the « Cardo maximus »—were mostly narrow and forming a maze.

2.2 PARIS BETWEEN 1652 AND 1790:

In the second part of the 17th century, Louis XIV decided the destruction of Paris’ enclosures, and the construction of the actual Grands Boulevards upon the Louis XIII’s enclosure.

Some planning rules also appeared in the late 17th century: new roads had to be large and as straight as possible. This said, except for the construction of the boulevards, no major urban project has been planned.

During this “no-wall” period, Paris passed through a classical process of centre-periphery expansion. Indeed, as mentioned in (Gherdevich & Noizet, 2014) the urban expansion of Paris before the 18th century followed a suburbanisation process: urbanisation took place on the access roads of the city, particularly in the left bank, but many areas remained empty between the new built up areas, creating a centre-periphery gradient. This urbanisation on rural ways was at the origin of the faubourgs.

Other townhouses appeared during this period, as well as many « ways of prestige » (Huard, ibid) at the entry of the city. Though, these ways were not a generator of urbanisation.

During the 18th century, only few operations of access and circulation’s improvement were planned. The intervention of the royal or municipal authority mostly consists in alignment or straightening of rural ways, and in fixing limits to the expansion of the city. This led to an urbanism of accumulation, with no planned urban project. Thus, the maze of narrow streets remained unchanged, as well as the plots.
Between 1784 and 1791, a new wall is constructed, the Wall of General Farmers, so as to establish a new tax territory in the city. The end of the 18th century also corresponds to the beginning of the French Revolution.

2.3 PARIS BETWEEN 1790 AND 1871:

After the Revolution, the clergy and aristocracy wealth were nationalised. Many buildings belonging to local and central government took on new functions (museum, schools, etc.). Other ones were demolished, freeing up land for new buildings and roads.

With the disappearance of the king and the urban hierarchy, urban planning was transformed. The Artistic Commission putted forward refurbishment plans for the city, with majestic avenues linking the various squares and monuments.

Besides, at the beginning of the 19th century, laws about properties' expropriation for Public utility were established (Huard, ibid). The aim of these laws was partly to wind up the urbanism of accumulation occurring so far. However, the pressure of demography was still squeezing, agricultural areas grew in value, and densification increased in new townhouses. At the same time, major infrastructures shaped the city such as the eastern railway (1840), and the Thiers' enclosure (1844).

The Second Empire (1851, 1870), namely the Haussmann period, witnessed an important modification of Paris' street network, with the creation of 175 km of new streets, representing one fifth of the total network of 845 km in 1871. Note that these new streets were superimposed on the former network, since no major expansion of the city has been planned during this period. This said, according to Salat (2011), this network deeply transformed the shape of the city while providing continuity to the existing roadway system. Indeed, the North-South and East-West crossroad was supplemented by a second network of concentric roadways, built using the remains of earlier road networks such as the actual Grands Boulevards and the Wall of General Farmers. On the left bank, the very irregular network along this Wall was straightened, reinforcing the concentric system.

Thereafter, we will analyse what happened in the form of the street network during each one of these interventions.

3. THE “MORPHOLOGICAL HISTORY”

Here we will first describe the datasets used to explore the “morphological history” of Paris' street network. Then we will present the method used to analyse them and finally the results of this analysis.

3.1 DATASETS:

Note that the choice of Paris as case study was due to the abundance of digitalised old maps of this city.

Our analysis was based on two main datasets. The first stem from the research programme ALPAGE, which purpose was to create a GIS platform containing data about the pre-industrial Parisian space. This platform contains the 1300 street network we used for the analysis, as well as a GIS file of the 1652's blocks, which has been exploited as a background to digitalise the street network of this year.

The second dataset is the GeoHistoricalData platform, a collaborative platform of digitalisation of historical maps. This platform contains the 1790 and 1871 street networks exploited in the analysis.

3 URL: http://alpage.huma-num.fr/fr/
4 URL : https://www.geohistoricaldata.org
Being based on the same process of construction, namely the georeferencing and the manual
digitalisation of old maps, then the data conflation and the use of matching tools; the two
datasets were mainly matching.

Furthermore, except for the 1300’s network, the chosen maps are known to be reliable: the
1652’s map is the first geometric map of Paris (Gherdevich and Noizet, ibid), and the reliability
of the 1790 and 1871’s maps was at the centre of many works (Dumenieu, 2015).

3.2 METHODS:

Based on previous researches, we chose to use network analysis so as to describe the form of
the network of each date. It basically consists of turning the road network into a graph, i.e. a set
of nodes linked by edges.

In the work presented here, a new geographical object, developed in (Lagesse, 2015), is used.
This geographical object is named the way. It is built according to the angle between each couple
of edges of the road network graph. The process considers iteratively each node, coupling the
edges according to their deviation angle (cf. figure 2). Doing so, the two edges with the minimal
angle of deviation will be paired and removed from the comparison. The remaining edges are
considered in the next iteration. This association is made with respect of a threshold angle fixed
at 60°: if the angle of deviation is superior to 60°, the edges will remain single.

Figure 2 - Pairing process. In this configuration, arc (or edge) i and arc l are paired, arc j and arc k remain a single as
they draw a deviation of more than 60°.

Once these pairing made, ways can be built using the examination of the list of paired edges.
The resulting geographical object is multiscale: it can be equivalent to one edge or be composed
of a large amount of edges, and cross the whole network. This construction is independent
from the way the network is read. Its parametrisation has been extensively studied by (Lagesse,
Bordin, & Douady, 2015).

The way is an association of continuous and aligned edges. It can be compared to the axial map
defined by Hillier (1984), except that the axes are not straight and have the actual geometry
of the road network. Following space syntax work, it is so possible to draw the dual graph
of the primal road network graph. In this graph, a way will be a node and an intersection between
ways will become the edges.

This dual graph will complete the primal one to elaborate indicators, based on topological
and geometrical properties of the network. Classical indicators of graph theory as well as new
ones, and their combination has been studied in a systematic way by Lagesse (2015). This Ph. D.
thesis shows that it is not possible to elaborate an infinity of indicators to characterize a
spatial network, some of them rapidly becoming redundant. It proposes a grammar of spatial
characterization, for edges as well as for ways, based on the study of road networks of four
cities, morphologically very different: Paris, Avignon, Manhattan and Barcelona.
This paper will focus on four particular indicators. Three of them are local (computed with the properties of the way itself and of its direct neighborhood):

- the degree: given by the number of other ways intersected by a way.
- the linear density: given by the relation between the length of a way and its number of connections (other ways’ edges intersected). A high linear density means that the number of connection is high while the length of the way is low.
- the orthogonality: given by the sum of the sinus of the intersected edges, divided by its number of connections. This indicator has been introduced by Lagesse (2015) and characterizes the geometrical inclusion of a way in the city road network. A high orthogonality means that ways are intersecting orthogonally.

One of the indicators considered here is global (computed using all the network):

- the closeness: given by the relation of the number of ways and the sum of topological distances from the considered way towards the whole network.

These four indicators are not redundant and bring very specific information on the spatial graph. Furthermore, they are robust to border effect and to small changes into the network geometry (Lagesse, 2015b). The information they highlight is thus independent of the chosen borders and to the small imprecisions linked to old maps digitalisation.

Once the indicators computed, our primary focus is to analyse their statistical distribution. Indeed, we consider the distribution of these indicators as good proxies to describe precisely the form of each network. Furthermore, this focus on the statistical distribution of indicators enables us to convert a “way level” measure (e.g. the degree of a way) into a “city level” one (the distribution of degrees in the whole city, its deviation comparing to a certain statistical law, etc.). This distribution is then compared from a period to another so as to identify change and permanence.

After that, we summarize, for each time frame, the evolution of the different indicators. We thus obtain a very accurate description of how the form of the network evolves during each time frame, and more generally throughout the 4 studied years. By doing so we will have revealed the “morphological history” of the network.

3.3 RESULTS:

The statistical distribution of the 4 indicators has been analysed following the same process: we first discretised it into classes, by choosing, for each indicator, bounds that suit each one of the studied years. This enables us to build the 4 years’ graphs with the same key, which is essential to make them comparable.

We systematically used the « nested averages » method so as to discretise each indicator, and each period. This method consists in using the average of the indicator (called m2), in 1300 for instance, so as to cut the distribution into two pieces. We then compute the average of each one of these pieces, to obtain m1 and m3.

We do the same thing with the other years. After that, we compute M1, M2, M3, which are respectively the averages of m1, m2 and m3 of the four years. We finally discretise all the distributions following the same bounds: 0-M1 ; M1-M2 ; M2-M3 ; M3-max.

3.3.1 LINEAR DENSITY:

The linear density distribution has been discretised into 4 classes. In 1300, most ways have a linear density in the two classes around the average. In 1652 in contrast, most ways have a very low linear density (between 0 and M1) and this phenomenon is strengthening in 1790, before slightly decreasing in 1871 (see figure 3).

5 Using a GIS Plugin named ©MORPHEO (Lagesse, 2015).
This distribution reminds us an inverse power law: huge number of low values, medium number of mean values, and small number of high values. Indeed, when we try to approximate this distribution with an inverse power law, the deviation indicator passes from 0,06 in 1300 to 0,002 in 1790, before increasing to 0,02 in 1871. This result may indicate that the linear density is converging, at least between 1300 and 1790, to an inverse power law distribution, which means that ways are getting longer and proportionally less connected.

Inverse power laws are typical of very hierarchized (unequal) structures: values are concentrated in one extreme, quite far from the average. Such structures have already been revealed in various traditional urban fabrics. For instance, Salat (ibid) demonstrated that the distribution of streets’ width, in historical cities, follows an inverse power law, with a big number of very narrow streets, and only few large avenues and boulevards.

A different phenomenon is occurring between 1790 and 1871. We will explore it in section 3.4.

![Figure 3 - Distribution of the linear density discretised in four classes (nested averages). The average (M2) upon which the discretisation was based is 0.04.](image)

The distribution of the degree in 1300 is also close to an inverse power law, due to the big number of ways with a degree of 2 (figure 5). This is increasing with time, since the deviation indicator passed from 0.02 in 1300 to 0.0001 in 1871. This result means that the distribution of the degree is being more and more unequal and that new ways are less connected (they mostly have a low degree).
Figure 4 - Distribution of the degrees without discretisation. We can observe the huge number of ways with degree 2, in the four years.

To make the figure clearer, we only represented the degrees from 1 to 14 (actually the maximum degree in 1871 is 116, against 40 in 1300).

Figure 5 - Distribution of the degree discretised in four classes (nested averages). The average (M2) upon which the discretisation was based is 4.68.

3.3.3. ORTHOGONALITY:

In 1300, most ways have a very high orthogonality, and only a few have a low one. The distribution changes in 1652 with a slight catch up of ways with average and low orthogonality. In 1790, the orthogonality is once again quite high, before changing radically in 1871, with a very equal distribution of the orthogonality, and no over-represented class. The tendency is thus towards variable kinds of orientations.
3.3.4. Closeness Centrality:

Being a global indicator, the closeness is strongly influenced by the size of the network. We therefore chose to weight it with the Napierian logarithm of the number of ways, at each period.

In 1300, the closeness seems pretty equal, but most ways are in the two classes under the average. This starts changing in 1652 and 1790, with an increase of the part of ways above the average. In 1871, the distribution has radically changed, with a predominance of medium and high closeness’ ways.

![Figure 6 - Distribution of the orthogonality discretised in four classes (nested averages). The average (M2) upon which the discretisation was based is 0.93.](image)

![Figure 7 - Distribution of the “closeness x log (number of ways)”, discretised in four classes (nested averages). The average (M2) upon which the discretisation was based is 1.52.](image)
3.4 WHAT THE RESULTS MEAN:

In what follows, we will summarize, for each time frame, the evolution of the different indicators so as to describe the evolution of the network’s form.

Between 1300 and 1652, the linear density and the degree are proportionally getting lower (closer to an inverse power law). This can be due to two phenomena: either ways are getting longer, or they are getting less connected, or both. Anyhow, it seems that the tendency in Paris is not towards adding intersections on short ways (which would increase the linear density), but rather absorbing longer and/or low connected ways. If we face this “morphological history” with the “event history” of Paris between 1300 and 1652, we can assume that this decrease in the linear density is due to the absorption by the city of rural sparsely populated (and thus low connected) ways during this period.

For its part, the orthogonality became more variable during this period, which means that various orientations appeared. This can be partly explained by the absorption of Charles V’s enclosure, and thus the appearance of non-orthogonal ways.

Lastly, a lot of ways got topologically closer during this period (cf. closeness). We can assume that this is due to the combination of longer and variably oriented ways described before.

Between 1652 and 1790, the “morphological history” of the network is mostly the same. Ways are getting longer and proportionally less connected, probably due to the suburbanisation process on the rural roads. We can however notice that the orthogonality and the closeness are highly increasing during this period. Indeed, many ways are getting more orthogonal and topologically closer. We will explore this aspect in the next section.

Between 1790 and 1871, the degree is once more getting closer to an inverse power law, but it is not the case of the linear density. Indeed, the number of ways with a “medium” linear density is increasing, and the global distribution is further from the inverse power law. It means that ways are either getting a little shorter, or a little more connected, or both. This can be the sign that the expansion process occurring so far in Paris was partly replaced by a densification process.

If we face this result with the “event history” of the city, we can assume that it was the impact of the pressure of demography and the densification of new townhouses in the first part of the 19th century. Furthermore, the Haussmann’s plan provoked a high increase in the number of streets (175 km of new streets) inside of the Thiers’ enclosure.

For its part, the orthogonality became much more variable, probably because of the concentric system of roads (made up of the Grands Boulevards and the former wall of General Farmers), and the refurbishment plans that aimed to link the various squares and monuments of the city. For its part, the increase in high closeness’ ways was probably due to the concentric system, as well as to densification of the network.

4. DISCUSSION

By facing the “morphological” and the “event” histories of Paris’ street network, we can identify two main processes: an expansion of the network between 1300 and 1790 (suburbanisation, ...), and a densification between 1790 and 1871.

The expansion process consists of carving out streets on the access roads to the city. The streets length thus increases, and (or) low connected roads are included in the city. This was highlighted by the decrease of the linear density. Furthermore, our results revealed that these moments of expansion correspond to a high orthogonality of the network. It means that the streets carved out during the expansion of the network are usually orthogonal. Concerning the closeness, it is usually in the average during these moments of expansion.

The second process is the densification of Paris, which occurred mostly between 1790 and 1871. Indeed, during this period, Paris did not expand much, but the density of its network highly increased. This was highlighted by the slight increase of its linear density.
On introduction, we considered the expansion and densification processes as *spontaneous* interventions as long as they are *unplanned*. The "event history" of Paris' street network confirms that these two processes were mostly unplanned.

This said, Paris' street network also passed through moments of planned interventions, mostly between 1790 and 1871. Indeed, the refurbishment plans of the Artistic Commission, then the Haussmann intervention clearly aimed at restructuring the street network, the former to link the various squares and monuments, and the latter to provide continuity to the existing network. It thus appears that the unprecedented densification of Paris between 1790 and 1871, as well as other factors such as the introduction of railways stations and, more globally, the Industrial Revolution, led to a pressing need for restructuring the network of Paris, and easing the circulation in the city. This was highlighted by the indicator of orthogonality, since ways of access' improvement are usually carved out non-orthogonally, so as to link two particular area of the city. As expected, these new ways led to an unprecedented increase of the closeness.

![Figure 8 - Sketches showing processes of expansion (A, B, C2) and restructuration (D).](image)

From the above, it seems that our four indicators were able to highlight different kinds of interventions. While the analysis of the linear density allowed us to distinguish expansion and densification processes, the analysis of the orthogonality and, to a lesser extent, the closeness, revealed more punctual and planned interventions. We can therefore conclude that the spontaneous interventions on street networks lead either to a decrease (when expansion) or to an increase (when densification) of its linear density. We can furthermore conclude that planned interventions do not radically change the linear density of the network – since a global tendency is emerging in our results. However, planned interventions usually have a higher impact on the orthogonality, by introducing various directions in the network, and on the closeness, by improving accessibility (see figure 8).

Of course, these are only hypotheses, based on the analysis of the city of Paris. The next stage would be to test these assumptions on other cities. Furthermore, the analysis of smaller times frames would probably gives further results, since it may allow to better distinguishing moments of spontaneous interventions, moments of planned ones, and to explore the impact of each one of them of the network's form. This will be the aim of further researches.
REFERENCES


DEVELOPMENT OF A CONFIGURATIONAL TYPOLOGY FOR MICRO-BUSINESSES INTEGRATING GEOMETRIC AND CONFIGURATIONAL VARIABLES

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ABSTRACT
In cities manifold actors are continuously taking decisions and proposing interventions, which are driven by, but also change, spatial conditions and their performance on a variety of scales. Understanding how this interplay works is crucial for urban designers and planners. However, this complexity asks for new methods of analysis or combinations of existing methods that better inform urban designers which is exactly what this paper is aiming at. The use of typologies to describe a complex reality has been both attractive to practice and an important research branch within urban morphology.

This paper presents a configurational typology that is not simply representing the physical environment, but rather its affordances (Gibson, 1979) where we use as example the conditions needed for various kinds of micro-businesses. It combines properties that describe the position of a specific urban block within the street network of a city, characteristics of the direct surrounding of a block as well as characteristics describing the plot configuration within a block. The spatial characteristics most often associated with the spatial organisation of activities were selected from literature.

The statistical method of two-step-clustering was used to distinguish clusters and thereby the different types of configurations. The clustering was tested in an explorative process to understand which characteristics were relevant to distinguish the main urban configurations of the urban system. The results are presented for the city of Amsterdam. The same method can be applied to other phenomena such as co-presence as well as other cities and thereby allows understanding the variety of such types, but also the existence of generic types. In a next step this typology could be tested for applicability in practise.

KEYWORDS
Configuration Typology, Urban Morphology, Space Syntax, Micro-Businesses
1. INTRODUCTION

In each city manifold actors are continuously taking decisions and proposing interventions that are driven by, but also change, spatial conditions and their performativity on a variety of scales. Understanding how this interplay of conditions, interventions and performativity works is crucial for urban designers and planners. However, its complexity asks for new methods of analysis or combinations of existing methods that better inform designers about the possible outcome of their interventions.

Martin and March identified in ‘the grid as generator’ (Martin and March, 1972) types based purely on geometric characteristics (Moudon Vernez, 1992). However, studies following this tradition also show shortcomings as these mainly examine the individual components of urban environments and how these relate to one another ignoring the system dimension of such components. To overcome this we integrated Martin and March’s approach with the space syntax approach (Hillier and Hanson, 1984). Typical for the latter approach is the explicit reference to “the position of any given space within the structure of the configuration of the whole” (ibid).

From a design theoretical perspective two aspects are important to the generation of new design proposals and a successful design process, that is a generative and an analytical theory (Moudon Vernez, 1992; Hillier, 1996). The latter, concerned with the actual effects of new proposals or its performativity, is far less developed (Marshall, 2012) to which this paper aims to contribute to by developing a configurational typology that allows for the evaluation of existing or created affordances (Gibson, 1979), that is, the evaluation of created possibilities.

These two aspects in design theory can also be recognized in a matrix presented by Gilliland and Gauthier (Gilliland and Gauthier, 2006) that summarizes differences and similarities between various approaches within the field of urban morphology (figure 1, authors interpretation). On the one hand the approaches are classed from being mainly generative-prescriptive (i.e. normative approach) to analytic-descriptive (i.e. cognitive approach). The other axis shows the focus of the approach spanning from being more interested in the internal characteristics of the urban environment (i.e. internalist approach) to being more focused on the social or economic factors influencing the evolution of urban form (i.e. externalist approach). Our concern now is mostly with the horizontal axis of the matrix between generative and analytic approaches.

What is important here is to mention that this matrix is not proposing a dichotomy between the two, generative/normative on one side and analytic/descriptive on the other side. It is easy to fall in that trap with practice standing on one side and research on the other. What is, however, of great interest, is the position in between where approaches such as environmental-behaviour studies, place studies and typology -morphology studies, we propose, can be located (see figure 1).
Figure 1 - An overview of the categorization of urban morphology research where typo-morphology, amongst others, is suggested to bridge between analytic/descriptive and generative/prescriptive research; freely based on Gauthier and Gilliland (2006, p. 46), Moudon (1992) and Berghauser Pont and Marcus (2015).

The typological approach presents great potential as it enables to include the complexity of the urban landscape both in terms of character and scale. Recent studies have shown the success of such approaches, e.g. Berghauser Pont and Haupt (2010), Gil et al. (2012), Barthelemy (2015). This is important for two reasons: First, to analyse urban conditions in its full complexity or, in other words, to evaluate the spatial characteristics and distributions in a city at all scales that, in turn, can accommodate diverse needs. Second, to inform urban development. It is especially here, typologies can be so powerful, because they enable to bridge between research and practice and we can make the full complexity of the urban landscape accessible for professionals in urban planning and design.

1.1 CONDITIONS FOR MICRO-BUSINESSES

The configurational typology presented in this paper focuses on the description of conditions for micro businesses in mixed-use environments. Micro businesses represent a crucial component of mixed-use environments, and have been in focus in many current visions and urban strategies, but little is known of how to actually spatially realise such a programmatic mixture to become true. Considering that activities are changing more frequently than physical form does, and emphasising the performative approach towards configurations, it is necessary to aim for a typology that is purely spatial, and not mixing form and function. We aim thus for an understanding of which configurations create what affordances, thus exploring possibilities rather than determining specialised spaces.

The literature review focussed first more generally on landscape ecology and urban morphology research, describing the general subdivision of land as well as its edges and transitional spaces (Vernez Moudon, 1994; Forman, 1995; Dramstad, Olson and Forman, 1996; Habraken, 2000). These morphological properties are important for a large range of social and economic processes in cities such as the distribution of economic activities (shops, production places, etc.) and social phenomena such as pedestrian flows.
In a second step, we looked more specifically on research from the field of space syntax where the main focus is on the configurative properties on the urban environment and often focussing on the influence of the street network configurations on economic activities (Hillier and Hanson, 1984; Marcus, 2008, 2010; Chiaradia, Hillier and Schwander, C., Wedderburn, 2009; Sardari Sayyar and Marcus, 2013; Scoppa, 2013). Recently, other than pure network-focused studies have been added such as studies on the effect of built density on economic activities (Berghauser Pont & Haupt, 2010), studies on the relation between retail and different aspects of urban configurations (Sevtsuk, 2010), micro businesses of service or production and different aspects of urban configurations (Hausleitner, 2010, 2014). All these researches provide interesting results on the relation of (micro-) business activities and urban configurations, but more research is needed in order to approach urban configurations in a more multi-scalar and systemic way and investigate, which configurations create affordances for which activities.

It is not the purpose of this article to come to a final understanding of the affordances of different urban configurations for different micro businesses; the construction of a configurational typology proposed in this article should rather be seen as the first step towards this understanding.

The range of spatial characteristics pointed out in the above-mentioned studies is wider than what will be considered in this paper. The characteristics smaller than the plot, for instance, were considered as not primarily systemic. Examples for those non-systemic spatial characteristics are the density of entrances per street segment length, the intervisibility for streets or the height of ground floors in buildings. Although these characteristics seemed crucial for micro businesses, they are not systemic and further, one cannot collect them citywide and will thus not be part of the developed typology.

1.2 TYPOLOGIES: DESCRIBING A DIVERSITY OF CONDITIONS

Investigating urban conditions from the morphologic perspective by means of a multi-scalar and multi-variable typology allows understanding the diversity of conditions within an urban system. Further it allows evaluating the potential of the different conditions as well as the affordance of the diversity of conditions in the whole urban system for future development on both, the local place and the urban system as a whole.

Typologies are used in favour of classifications to distinguish urban environments, because classifications refer to an explicit distinction of characteristics, whereas types can share partially similar components (Hempel and Oppenheim, 1936). A typology can thus represent better urban environments built from multiple components. Some types may have similar shared components. The specific composition of multiple characteristics though shape distinctive types of urban configuration.

When it comes to identifying urban types, two approaches are used within urban morphology. The first, known as the Italian school following the work of Muratori (Muratori, 1950, 1955; Muratori et al., 1963) and Caniggia (Malfroy and Caniggia, 1986; Caniggia and Maffei, 2001), identifies types as ‘cultural entities rooted in, and specific to, the local process of cultural development’ (Kropf, 2009). Although the Italian school of morphology already described typological elements on the larger scale in the morphological studies of Genova, Rome, Florence and Venice, there was no method to compare spatial conditions on the extent of a whole urban system, with a higher resolution detail, as the urban block or building (Caniggia and Maffei, 2001).

The second approach builds on the work of Martin and March presented in ‘the grid as generator’ (Martin and March, 1972) and identifies types based purely on its geometric characteristics (Moudon, 1992). The latter fits our aim better as we are interested to study spatial characteristics independent from the process of development or evolution over time and independent from the affordances it creates. Martin and March’s approach (ibid) of quantifying urban environments became important for two reasons: first, to understand the complexity of entire spatial systems and specifically the relation between its elements, and second, to achieve a higher precision in the understanding of urban form.
However, studies following this tradition also show some serious shortcomings as these mainly examine the individual components of urban environments and how these relate to one another ignoring the relative or systemic dimension of such components. To overcome this, we propose to integrate Martin and March’s approach with another approach in urban morphology described by Kropf (2009) as the configurational approach, better known as the space syntax approach (Hillier and Hanson, 1984). Typical for this approach is the explicit reference to “the position of any given space within the structure of the configuration of the whole” (ibid). Together these cover what Moudon (1992) described under the heading space-morphology.

Section two presents a method to identify configurational types that are integrating intrinsic characteristics (i.e. individual components) of an area and extrinsic or configurational qualities, that is, its position in the city structure as a whole. In the third section, the configurational typology is presented for Amsterdam. Besides the identification of types and its geographic distribution in the city, differences and similarities between the types will be discussed. In the last section the applicability of the method in urban design practice will be discussed.

2. METHOD

The method to develop a configuration typology consists of following steps: first, defining the aggregation unit, second, selecting a set of relevant spatial properties, third, calculating the properties per aggregation unit, fourth, organising the information per aggregation unit in a geo-database and fifth, distinguishing the configuration types by using a non parametric statistical clustering method.

The study area includes for the building of the typology the complete city of Amsterdam, keeping an additional zone of 5km around the municipal borders to prevent possible boundary effects. The final representation of the configurational typology includes all neighbourhoods of the municipality of Amsterdam, which comprise residential or residential and business activities.

First, the aggregation unit, the urban block was defined. The urban block was chosen as aggregation unit, since it relates the city scale configurational and morphological properties with the scale of the individual parcel or plot. Although aggregating on the urban block has limits due to not considering the influence of variations of the blocks’ surrounding streets on the different faces of the urban block, the unit of the urban block is still the most commonly used in urban design and planning practise to set rules for development. When looking at the basic block file of the city of Amsterdam, it became obvious that the definition of ‘urban block’ was not coherent in the whole city. The block outline partially equalled the building outlines, and in parts described what we know as closed urban perimeter blocks, being assembled from many buildings. The first was not done, because the buildings covered an urban block, but rather showing the distinction between built and un-built, or sometimes the distinction between public and collective, corporative or private ownership. This way of representation and definition allowed a conclusion on the compactness of the urban areas, but made it impossible to evaluate the potential of an urban configuration for different urban programme. Thus in the first step the borders of the urban blocks of Amsterdam were redrawn, representing in the new version units that were separated through public streets. Since this typology was developed as part of a research concerned with mixed use and residential tissues in Amsterdam, administrative neighbourhoods containing only business parks or industrial platforms were not included in the survey. Therefore 4835 urban blocks are covered by the configurational typology.

Following urban morphological characteristics were selected from literature to build a configurational typology that allows a comparison of spatial conditions throughout the whole city. They describe grain (size, fragmentation, density, edge condition) and accessibility, and refer to different scales, see figure 2 for the overview of properties and the scales they belong to.
DEVELOPMENT OF A CONFIGURATIONAL TYPOLOGY FOR MICRO-BUSINESSES INTEGRATING GEOMETRIC AND CONFIGURATIONAL VARIABLES

To make the measures comparable either indexes were used or density values, referring to ha. A set of ten measures (including black and grey printed items in table 1.1) was used to explore which ones can distinguish configuration types formed through the clustering. In the following the ten measures, which are all aggregated on the urban block, are described:

2.1 GRAIN RELATED MEASURES:

2.1.1 STREET NETWORK DENSITY (IN M/HA)

Streets are very stable parts of the tissue, and mostly are built before the buildings grow assembled in islands or blocks. The network is primarily defined as 'infrastructure with a certain structural robustness’ (Berghauser Pont and Haupt, 2005). The system of the network of the public streets regulates the composition of the urban blocks (Meyer, 2005). Jane Jacobs (1961) points out that ‘frequent streets and short blocks are valuable because of the fabric of intricate cross-use that they permit among the users of a city neighbourhood’. But the property of a dense street-network has to be supported also by other morphological parameters as well as governance parameters, because ‘by too repressive zoning, or by regimented construction that precludes the flexible growth of diversity, nothing significant can be accomplished by short blocks’ (ibid.). Generally, a block and its adjacent streets are interrelating and the properties of both need to contribute to achieve vital neighbourhoods. The street-network density was calculated in m/ha, considering all streets in a square of 800/800m from the centroid of each urban block. The street length is expressed in m/ha.

2.1.2 PARCELLATION (PLOTS/HA)

The amount of plots within a block was for a long time a model to structure urban territories, whereby “the system of plot division [is] strongly influenced by the system by which land is made available” (Meyer, 2005). The division of a block into plots allows a development spread over time as well as shared responsibilities. Further the structure of the plot division is an important contribution to the appearance of an area, as it supports sequencing along a street as well as probably a greater variety in design, with the pre-requiment of additional diversity.
of ownership. For the parcellation the amount of plots within an urban block were aggregated per block and normalised by the block size, and is therefore expressed in plots/ha.

2.1.3 EFFECTIVE MESH SIZE (IN HA)

The effective mesh size describes the fragmentation of the urban block and is hence an indication of the inner accessibility of the urban block. This property is derived from research on landscape ecology, describing landscape fragmentation (Jaeger, 2000). It is used to consider a blocks’ internal fragmentation, which resembles the smallest independent grain. What on the one hand is increasing the permeability of the network can have fragmenting effects on the block scale. This measure is used here also to consider the effect of block internal streets and paths, which are known as crucial for the location of manufacturing businesses in the inner parts of larger urban blocks. The measure of the effective mesh size denotes the size of the areas when the region under investigation is divided into S areas (each of the same size At/S) with the same degree of landscape division: m=At/S (ibid).

2.1.4 BUILT DENSITY (GSI, FSI)

Built density can be expressed in three different measures: the building intensity (FSI), Coverage or Compactness (GSI) and Spaciousness (OSR). Density is approached here as multi-variable phenomenon calculating FSI, GSI and OSR by means of the plan area, built-area and gross-floor area using Spacematrix developed by Meta Berghauser Pont and Per Haupt (2010). This method allows to draw conclusions on the distribution of density within a block, hence also on the influence of the specific built density on urban programme. For the cluster definition the two density indexes GSI and FSI are calculated, with the plan area being the brute block surface. GSI is calculated by dividing built area / plan area. FSI is calculated by dividing the gross floor area / plan area.

2.1.5 OPENNESS OF THE URBAN BLOCK’S PERIMETER (% OF BOCK BORDER)

The openness of the block or island perimeter is defined by the share of total border length accompanied by buildings and is measured in percentage. The openness of a block perimeter or the locations of buildings on a plot/in a block contribute to the definition and legibility of public and private realms. Further, higher or lower distance of a facility to the public space influences the suitability of a facility for certain types of businesses.

2.2 ACCESSIBILITY RELATED MEASURES

2.2.1 STREET-NETWORK-CENTRALITY MEASURES

The integration of the block in the city in general sets potentials in a wider context for what programme can succeed in an urban block. Being a property of the street-network, the topological integration analysis visualizes the potential of a street to be approached (integration) or used to pass through (choice). The method of Space Syntax developed by Bill Hillier and associates is used to calculate and visualize the configurational analysis that adds to the concept of connectivity the concept of depth, which is measuring the network distance steps of adjacency between network components, compare Hillier (1996) and Marshall (2005). Four measures are used to analyse vicinities to different centralities within the whole street network system of a city. These are on the city scale: Topological Choice 10.000metric and Topological Integration r N. On the fabric scale the measures are topological choice 80ometric and topological integration r 3. The radius depends on what resolution we look at the city. The radius used to understand the integration of a street in the urban system is 1km, which refers to the complete urban system of Amsterdam, whereas the local radius used is 800m, referring to local distance in the Netherlands.

The values for all four measures are calculated using the program Depthmap by Space Syntax, whereby each street or street segment is assigned a specific value that allows understanding the role of each street in the whole urban system.
2.3 TWO-STEP CLUSTERING

All ten measures were aggregated on the urban block according to the descriptions per property above and the derived information was further organised in a geo-database. For the database each urban block was assigned a unique identification number, which were used to relate the information from the property calculations to the geometric shapes in the geo-information system. The geo-database built the base for the following step of statistical cluster analysis.

The requirements to build this configurational typology were first to employ a multi-scalar approach serving the complexity of urban systems. The construction of this kind of typology allows comparing spatial conditions on the city or regional scale. In order to build a typology automatized, the statistical method of two-step-clustering was used. This non-parametric method allowed the distinction of clusters without the necessity of basing on normally distributed data, which is often not the case when analysing spatial data.

The two-step cluster analysis is an explorative statistical method, which means that the final set of clusters is achieved after testing multiple variants – we tested for two clusters as minimum up to seven clusters. Additional requirements when building this typology were that all blocks were covered by the typology, the model of the clustering was at least fair, that all input morphological characteristics were of high predictor importance and that the ratio between the largest and smallest cluster was not too big in statistical terms. The clustering was tested in an iterative process with different input properties until all requirements were satisfied.

The automatized clustering found two clusters, distinguishing basically between the open and closed block city. This distinction represents the most general difference, is though for our purpose too rough to distinguish further differences of urban conditions. An example for this is that a closed urban block in a segregated location gives complete different conditions for possible urban programme or urban qualities than a closed urban block in a very central location. On the contrary a higher amount of clusters becomes too detailed and produces partially very small cluster sizes, which are not representative anymore on the city scale. Some characteristics were not relevant to build the typology because they had either low or no predictor importance, which was based for example on a too homogeneous manifestation of a characteristic on the city extent, like the street network density. The final cluster distinction is presented in the following section.

3. RESULTS

The final cluster distinction shows six different configuration types (see figure 3), built multi-scalar from five different urban morphological characteristics1. These are compactness (GSI) and intensity (FSI) of built space, openness of the urban block, the amount of plots/ha and the topological choice on the city scale (radius 10km). The other morphologic properties were not considered after the clustering tests, because they don’t seem to highlight differences between types. Interesting to observe is that the properties on fabric scale (see the grey written parts in figure 2) were not important when distinguishing differences in the urban system, at least when it comes to micro businesses. Remarkable is hence that the typology is built upon morphologic properties from the city scale and from the urban block scale. The reason that street network density does not seem important is that it does not show in enough variability in Amsterdam. This does not mean that the variable as such is not important concerning the location of micro businesses but rather that it is not important to distinguish types in Amsterdam on the city scale.

The six types in Amsterdam comprise 4,865 urban blocks with the following size: n (Cluster1)= 839 urban blocks, n (Cluster2)= 339, n (Cluster3)= 759, n (Cluster4)= 676, n (Cluster5)= 1153, n (Cluster6)= 1069. (figure 4 presents maps of each individual type).

1 The five morphological and configurational variables were tested for collinearity in SPSS. The Variance Inflation Factor (VIF) values showed mainly values below 2; GSI showed values around 3 for the variables of topologic choice 10.000 and plots/ha. From these results we concluded that there is no considerable collinearity among the variables.
DEVELOPMENT OF A CONFIGURATIONAL TYPOLOGY FOR MICRO-BUSINESSES INTEGRATING GEOMETRIC AND CONFIGURATIONAL VARIABLES

Figure 3 - The configurational typology for Amsterdam. Overview of the six types and their distribution

Type 1. This configuration type consists mainly of blocks with a high regional topological choice value, which indicates a high potential of passers-by at these urban blocks considering the street network of the whole city. The borders of these urban blocks are rather closed, being maximum 30% open. The blocks are built with medium compactness and with a medium to high built intensity. The parcellation shows a rather wide range of values per hectare in this configuration type, no real high values though.

Type 2. The main defining morphological property for this configuration type is the very high compactness as well as intensity of built form. The blocks are predominantly closed or mainly closed. The parcellation shows a rather fine grain and the blocks are located along streets with lower to medium regional topological choice.

Type 3. This configuration type is defined by a high compactness and with exception only closed urban blocks. The blocks of this fabric type are located along streets with medium regional
topological choice values. The built intensity shows medium values. The parcellation density appears in a rather wide range of values, which means an integration of fine grain and bigger grain parcellation.

Type 4. This configuration type is characterised by a very low built intensity, at the same time a very fine-grained parcellation, which relates to the building types of single-family homes. The compactness of built mass is low to medium and the urban blocks of this configuration type are located at streets of lower to medium regional topological choice values. The border of the urban blocks in this kind of configuration is half open to nearly closed.

Type 5. This configuration type consists mainly of blocks with quite large grain of parcellation, covered by a medium built compactness. The built intensity is low to medium. The streets of this urban configuration type have lower to medium regional topological choice values. The urban blocks show a broad variety of openness – from rather completely closed to very open.

Type 6. This configuration type is characterised by a very low built compactness and at least half open blocks. The parcellation of this configuration type is of rather large grain. These first three characteristics also relate to the presence of the large housing estates built in the 1960s that also can be found in this configuration type. The general built intensity of this configuration type is low and its streets show a very wide range of regional topological choice values, from very low integrated to very high-integrated streets.
Some of the types clearly concentrate in certain parts of the city such as type 1 which dominates the areas built until the beginning of the 20th century. Although this concentration of the configuration type is visible, we can find this type of configurations also in all other districts of the city. The same is valid for the other configuration types.

These six types build a configurational typology that includes both, morphological and syntactical characteristics and as such is able to capture both what conceived space (blocks, squares, etcetera as items per se) and perceived space, (Lefebvre, 1974; Ståhle, 2008) taking into account the way we move around in the city, making the street space more important than the urban block that one never experiences as such. Moreover, this typology has a dynamic character, which can proof highly important for its applicability in practice. With "dynamic" we mean the belonging of a block to a certain type can change from one day to the other as a street is closed off for traffic which in turn changes the topological choice values for the whole city.
and possibly turning one or more blocks from being of one type to becoming of another type. As discussed earlier, this creates other potentials for various social and economic processes; in our case micro businesses that we know are related to these spatial characteristics. How exactly was not the aim of this paper, but will be central to another paper we prepare in which these types will be related to the distribution of micro-businesses. For the urban design practice this can be of high importance as intervening in the city is what designers do all the time. A configurational typology that changes with these interventions and as such can give feedback to the urban designer is more valuable than a static typology that cannot show impacts of spatial interventions.

4. DISCUSSION

The reading of an urban system through this kind of typology can be seen as an unfolding of potentials, and assessing affordances. The important and new aspect of this typology is that it allows identifying similar spatial conditions in different parts of the city. Even though a certain configuration type dominates each part of the city, we can find them in all areas of the city. That means that we can find divers spatial conditions in all parts of the city. Some areas show more homogeneous configurations; other areas are more diverse. The effect of more homogeneous or diverse configurations will be elaborated in further work.

In general, we can understand from the typology that urban morphologic characteristics of topological choice and built density combine in specific ways in certain areas in the city, something that is indicated in Hausleitner (2010) and discussed more in detail in Berghauser Pont et al. (2017). Whereas the different characteristics on their own represent components of urban morphological configurations, the relation between them manifests the types that build the performance base for different urban programme (in our case for micro businesses), and allow for evaluation of the affordance of an area and is thus analytic and generative at the same time.

The multi-scalar typology presented here is integrating five morphological characteristics: the division of a block into plots, compactness (GSI) and intensity (FSI) of built form, the location of a block regarding the topological choice of the surrounding streets relating to the complete urban street system, and finally the openness of the block. The topological choice measure explains the potential of a block to be passed-by in the system of streets. The division of an urban block into plots allows conclusions on the grain size and thus possible density of activities, being complemented on the block scale by FSI and GIS explaining capacity of the built material to accommodate activities. Openness as additional measure allows conclusions on the possible amount of interaction between the public street and the uses inside buildings. This measure also allows drawing conclusions on proximity or distance of uses from those inside and to other blocks. A low openness means that the border between the public and private is rather immediate. The façades of most buildings run along the block border. This does not mean that these facades are actually active, but the potential of being active, for interaction between the public and the private is there. The configurational typology for micro businesses presented here allows a characterization of the whole urban system in a systemic and precise way. Its meaning for other kind of activities and possible transferability to other systems are important issues to be elaborated in future research.
REFERENCES


ABSTRACT

Many studies have looked at the measures of existing street networks, analysing dense, traditional urban areas and sparse, suburban areas. In most cases, these studies contrast the two extremes to describe both quantitative and qualitative differences. Cervero and Gorham (1995) analysed the scale of road segments to distinguish automobile versus transit-oriented neighbourhoods. Siksnas (1997) examined block size and its effects on urban development. Hillier (1999) analysed the intelligibility and connectivity of several city centres to describe the local principles of city growth and their impacts on sustaining strength and vitality. Jacobs (1993), Major (2015), and Peponis, Allen, Haynie, et al. (2007) illustrated significant differences in the scales and densities of various neighbourhoods of historical influence. Few have looked at the American city comprehensively and tried to adequately depict its more common morphological characteristics. In response, this work establishes a description of the measures of street connectivity for existing street networks, as they occur across the American city, and creates a comparative database to describe the multitude of urban morphologies encountered.

A comparative database of 4,321 local areas, each measuring 2-miles in diameter, is created from the 24 largest Metropolitan Statistical Areas. These local areas are sampled randomly to capture, with equitable probability, an even distribution across each metropolitan region. Four measures describing street connectivity – length, block area, metric reach and directional distance, are averaged for the road segments and blocks within each local area and analysed to define a range of measures. Distributions, frequencies, and interquartile ranges are examined to determine the most often encountered measures of street connectivity within these selected MSAs. Lastly, measures are benchmarked against noteworthy street networks (Peponis et al., 2007), particularly those with distinguishing characteristics like Riverside (Chicago), Levittown (Philadelphia), Radburn (New Jersey), and Reston (Virginia).

Acknowledged distinctions between the measures of these MSAs are captured by their associated means, and yet, few differences are demonstrated through their modes, or frequency intervals capturing the measures most often encountered. As a general characterization, the scale, density, and circuitousness of existing street networks far exceeds the anticipated range of measures. Most local areas of the random sample are significantly longer in their average length of road segments, larger in their average area of blocks sparser in their average metric reach, and more circuitous in their directional distance than even the most sprawling suburban areas originally considered. If the goal of a street network is to fundamentally ‘connect spatially separated places,’ as suggested by Handy, Paterson, and Butler (2003), then clearly this study demonstrates that there is much work to be done within the American metropolitan region.
KEYWORDS
American cities, urban morphology, street networks, street connectivity

1. INTRODUCTION

Many studies have looked at the measures of existing street networks, analysing dense, traditional urban areas and sparse, suburban areas. In many cases, these studies contrast two extremes to describe both quantitative and qualitative differences related to modes of transportation, land use, density, and connectivity. Cervero and Gorham (1995) analysed the scale of road segments to distinguish automobile versus transit-oriented neighbourhoods. Siksna (1997) examined block size and its effects on urban development. Major (2015) compared urban grids in American cities to those in Europe, illustrating the immense differences in the scale of block area and line length.

Others have sought to examine a range beyond the established contrasts in spatial processes and urban forms. Hillier (1999) analysed the intelligibility and connectivity of several city centres to describe the local principles of city growth and their impacts on sustaining strength and vitality. Jacobs (1993), Southworth and Owens (1993) and Peponis et al. (2007) illustrated significant differences in the scales and densities of distinctive types of neighbourhoods to establish an expected range of measures. Marshall (2005) critically reviewed the nature of various street networks and proposed a matrix of four types.

Of these case studies, familiar street networks were selected for their historical, morphological and/or planning significance. Few have looked at the American metropolitan area comprehensively and tried to adequately depict its more common morphological characteristics. In response, this work samples street networks randomly, as they occur across the American metropolitan area, and assesses four measures of street connectivity to create a comparative database of measures.

2. DATASETS AND METHODS

To more broadly understand the morphological characteristics of the American city, local areas were sampled randomly from 24 of the most populated American metropolitan areas. In premise, these metropolitan areas represent an array of geographical conditions and historical planning influences, adequately capturing its many morphological characteristics. Samples are selected randomly from Atlanta, Baltimore, Boston, Chicago, Cincinnati, Cleveland, Dallas, Denver, Detroit, Houston, Los Angeles, Miami, Minneapolis, New York City, Philadelphia, Phoenix, Pittsburgh, Portland, San Diego, San Francisco, Seattle, St. Louis, Tampa, and Washington D.C.¹

Sampling was structured to capture ten percent of the total area of each Metropolitan Statistical Area (MSA), using an established framework to ensure an even distribution and equitable probability for the random sample. The framework was defined by a politically significant point of centre², radiating rings that established distance from that point of centre, and a coordinate system to delineate North, South, East and West. From each section of this established framework, x and y coordinates were randomly selected, and a provision was included to eliminate the potential of overlapping areas.

¹ For consistency in defining each American city, the boundary of the Metropolitan Statistical Area (MSA) was used, as defined by the U.S. Census Bureau in 2000. In several instances, established urban areas of development cross MSA boundaries. In these cases, the data files for each MSA are joined. These instances include the union of Cleveland with Akron, Denver with Boulder, Los Angeles with Riverside and Ventura, Philadelphia with Trenton, and San Francisco with San Jose.

² Similar to French and Scoppa (2007), the rings radiated outward from the point of centre at five-, fifteen-, thirty-, and sixty-mile intervals.
Using these coordinate pairs, circular buffers, measuring 2 miles in diameter, were constructed, and road segments, blocks, and their associated measures were extracted. For consistency, those road segments and blocks that were completely contained within and those that intersected each buffer were extracted from the larger context of the metropolitan area. Pairs that fell outside the political boundary of the MSA were discarded (Figure 1).

Many of the circular buffers captured significantly more block area or road segment length than was initially intended. Rural areas, containing extremely large blocks and long road segments, were captured because of the U.S. Census Bureau’s method in defining a MSA politically, in lieu of economically or morphologically. Similarly, small extremes, or residuals resulting from the way in which the Esri maps were drawn, were also captured. The inclusion of such extremes, at either scale, greatly affected the statistical summaries, distributions, and confidence in the inferences. As a result, road segments and blocks of extreme scale, both large and small, were identified and excluded to ensure more discerning conclusions.\(^3\)

The resulting, random sample consists of 4,321 local areas, measuring two-miles in diameter, across all 24 American metropolitan areas. It provides a means for examining the morphological characteristics of the existing street networks in the American city – their measures of connectivity and central tendency. It also provides an extensive sample to benchmark measures of street connectivity against those of the more familiar, historically significant local areas known for their distinctive morphological characteristics.

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\(^3\) To prevent potential distortion from extremes within the database, the work of Thomas Jefferson and his influence on the Land Ordinance of 1785 (Rashid, 1996) was assessed in conjunction with the work of Doxiadis (1965) and Krier (1976) to set parameters for pragmatically defining and removing extremes. Blocks more than 640 acres in area or less than 0.12 acres were excluded. Similarly, road segments more than 1 mile in length or less than 72 feet were excluded.
2.1 LIMITATIONS OF THE DATA

The automated process in collecting data created a substantially larger and statistically significant sample for analysis, but it is not without limitation. The aggregate size of the random sample made it impossible to examine the data to correct and edit errors. As a result, the data is only as good as the original data sourced from Esri. Second, street centre-line data was used to construct the blocks within this data set, without consideration of street width, affecting measures of block area. Lastly, unlike those neighbourhoods previously studied in the literature by Peponis et al. (2007), many of the local areas sampled here are not complete, congruent sets of road segments and blocks. Consequently, aggregate measures of connectivity, like density, and their associated statistical correlations, should be analysed carefully.

2.2 MEASURES OF STREET CONNECTIVITY

Many measures have been used to describe street connectivity (Dill, 2004; B. Hillier, 1996; Peponis, Bafna, & Zhang, 2008; Turner, 2007). For this case study, four measures—road segment length, block area, metric reach and directional distance, are analysed for the road segments and blocks within each local area and analysed to establish a range. Road segment length and block area are used to capture morphological characteristics of scale. Metric reach is used to capture the density of a street network, and directional distance is used to describe the configuration, or the directness, of the streets within each local area. Parameters for metric reach are set at 1 mile (1.6 km), to capture the average walking distance for pedestrians in an American city, and those for directional distance are set at 1 mile (1.6km) and 10 degrees.

For convention, statistical measures for the random sample of local areas (RSLAs) will be referenced as the following: length (LA) describes the average length of road segments within a particular local area; the mean of length (RSLA) describes the average length for all 4,321 randomly sampled local areas; and the MSA mean of length (RSLA) describes the average length for the randomly sampled local areas within a particular American metropolitan area. Other measures, as reported here, are referenced and calculated similarly, i.e. the mean of block area (RSLA), the mean of metric reach (RSLA), and the mean of directional distance (RSLA).

3. RESULTS

When measures for these RSLAs are analysed, the mean of length (RSLA) measures 1382.66 feet, the mean of block area (RSLA) measures 134.24 acres, the mean of metric reach (RSLA) measures 9.28 miles, and the mean of directional distance (RSLA) measures 4.85 changes in direction for the captured reach (Table 1). When compared to historically and morphologically significant areas, as defined by Peponis et al. (2007), the mean of length (RSLA) is substantially higher than those sprawling suburban areas of Reston (Virginia) and Crabapple (Atlanta). The mean of block area (RSLA) is also higher, though only slightly. The mean of metric reach (RSLA) is lower than most of the notable areas, and yet, the mean of directional distance (RSLA) is within the range.

Given this extension to the previously established range of expected measures, particularly for the measures of length and area, the interquartile range, or the difference between the first and third quartiles, is also described to give a sense of the asymmetry in the distributions. As reported in Table 2, the interquartile range of length (RSLA) measures 1105.36 feet, suggesting significant skewness within the distributions. Similarly, the interquartile range for the mean of block area (RSLA) measures 177.14 acres, which also suggests significant skewness. In contrast, the interquartile ranges, for both the mean of metric reach (RSLA) and the mean of directional distance (RSLA), are substantially lower, indicating less skewness. The interquartile range for the mean of directional distance (RSLA) is 3.73 changes in direction for the captured reach (Table 3).

4 When calculating length (LA), (n) will vary given the number of road segments captured in each local area.
5 When calculating the MSA Mean of Length (RSLA), (n) will vary given the number of local areas captured within each MSA. The number of local areas captured within each MSA is reported in Table 3.
distance (RSLA), suggest a more normal distribution. The interquartile range for the mean of metric reach (RSLA) measures 7.01 miles, and the interquartile range for the mean of directional distance (RSLA) measures 3.44 changes in direction.

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<tr>
<th></th>
<th>Mean of Length (feet)</th>
<th>Mean of Block Area (acre)</th>
<th>Mean of Metric Reach (1 mile) (miles)</th>
<th>Mean of Directional Distance (1 mi./10 deg.) (changes in direction)</th>
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<td>530.41</td>
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<td>15.33</td>
<td>8.99</td>
</tr>
<tr>
<td>Crabapple (Atlanta)</td>
<td>630.28</td>
<td>106.77</td>
<td>8.99</td>
<td>8.62</td>
</tr>
</tbody>
</table>

* Data for these historically and morphologically significant local areas was sourced from Peponis et al. (2007), with the units of meters and kilometres manually converted for comparison.

Table 1 - Statistical Measures of the Random Sample of Local Areas (RSLAs) compared to several Morphologically Significant Areas already defined within the existing literature angular choice weighted by segment length in the case study areas.

Given the significant differences illustrated by the interquartile range, particularly for length and area, distributions are examined in further detail. For the 4,321 RSLAs, the distribution of length (LA) illustrates positive skewness across a wide range of measures (Figure 2a). With the bins in the histogram distribution set at 100 feet, the mode for length (LA) measures 500–600 feet and captures 10 percent of this sample set. Notably, 58 percent of the RSLAs measure, on average, less than 1200 feet in average length. Similarly, the distribution of metric reach (LA) illustrates positive skewness across a wide range of measures, but most the local areas are clustered around a much narrower range (Figure 2b). With the bins of the histogram distribution set at 5 miles, the mode of metric reach (LA) measures less than 5 miles and captures 43 percent of this sample set. Notably, 93 percent of the local areas measure, on average, less than 25 miles of reach. Distinctly different from length and metric reach, the distribution of directional distance (LA) illustrates a more normal distribution (Figure 2c). With the bins of the histogram distribution set at 2 direction changes, the mode of directional distance (LA) measures more than 2 but less than 4 direction changes and captures 31 percent of this sample set. Notably, 58 percent of the local areas measure less than 5 changes in direction, on average, to navigate the distance captured by metric reach.
For block area (LA), the distribution also illustrates positive skewness across a wide range of measures (Figure 3a). With the bins in the histogram set at 20 acres, the mode of block area (LA) measures less than 20 acres and captures 20 percent of this sample set. Among local areas that are less than 20 acres, on average, the distribution illustrates a bimodal distribution with a primary spike at 4–6 acres and a secondary spike at 10–12 acres (Fig 3b).

When comparing the mean of length (RSLA), block area (RSLA), metric reach (RSLA), and directional distance (RSLA) to those more familiar areas with distinct morphological characteristics, the established range is substantially expanded. Only 17.6 percent of the local areas in the sample measured less than 600 feet, on average, in length (LA), and only 17.1 percent of the local areas exhibited a measure of metric reach (LA) more than 15 miles, demonstrating that a significant proportion of the randomly sampled local areas are even larger and more poorly connected than originally anticipated. These results raise the question: how does distance from the metropolitan centre, and in particular, the sampling method for these local areas, affect the results reported here?

To ensure equitable distribution in the sampling of local areas randomly, the established framework extracted more local areas from the periphery of each metropolitan area. As established within the literature (French & Scoppa, 2007), areas at the periphery and those often described as sprawling suburban neighbourhoods exhibit increases in their measures of length (LA) and block area (LA) with associated decreases in their measures of metric reach (LA), particularly when compared to those at the metropolitan centre. Presumably then, there are more local areas greater in scale and lower in density for this set of RSLAs, and because of their proportions, they could have greater influence on the statistical measures like mean and interval mode. As a result, the distributions and frequencies of length (LA), block area (LA), metric reach (LA), and directional distance (LA) are studied for only those 521 local areas within a fifteen-mile radius of the metropolitan centre to assess the effects of distance on the measures reported here.

Table 2 - Quartile Measures of Length (RSLA), Block Area (RSLA), Metric Reach (RSLA), and Directional Distance (RSLA)

<table>
<thead>
<tr>
<th></th>
<th>Maximum</th>
<th>75.0%</th>
<th>Median</th>
<th>25.0%</th>
<th>Minimum</th>
<th>Interquartile Range</th>
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</thead>
<tbody>
<tr>
<td>Length (RSLA)</td>
<td>5275.16</td>
<td>1801.76</td>
<td>1193.43</td>
<td>696.39</td>
<td>117.96</td>
<td>1105.3670</td>
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<td>Block area (RSLA)</td>
<td>638.869</td>
<td>202.495</td>
<td>75.610</td>
<td>25.357</td>
<td>0.1256</td>
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<tr>
<td>Metric Reach (RSLA)</td>
<td>78.3917</td>
<td>11.0025</td>
<td>5.5704</td>
<td>3.9945</td>
<td>0.0223</td>
<td>7.0080</td>
</tr>
<tr>
<td>Directional Distance (RSLA)</td>
<td>27.4721</td>
<td>6.3547</td>
<td>4.4678</td>
<td>2.9113</td>
<td>0.0000</td>
<td>3.4434</td>
</tr>
</tbody>
</table>
MORPHOLOGICAL CHARACTERISTICS OF THE AMERICAN CITY
A case study benchmarking measures of street connectivity

Figure 2 - Illustration of the Distributions for Measures of Length (LA), Metric Reach (LA), and Directional Distance (LA). Measures for all 4,321 RSLAs are included in figures (a), (b), and (c). As a test to examine the effects of distance on the distribution, only measures for those 521 RSLAs within 15 miles of the city centre are included in figures (d), (e), and (f).

Figure 3 - Illustration of the Distributions for Measures of Block Area (LA). Measures for all 4,321 RSLAs are included in figures (a). Measures of those 4,321 RSLAs with an average Block Areas (LA) less than 20 acres are included in figure (b). Again, as a test to examine the effects of distance on the distribution, only measures for those 521 RSLAs within 15 miles of the city centre are included in figure (c), with those measuring less than 20 acres, on average, in figure (d).
When examined, the measures of length (LA), block area (LA), and directional distance (LA), as they occur at the periphery, are not significantly affecting the distributions. For this subset of local areas within a fifteen-mile-radius of the metropolitan centre, the distributions demonstrate modes of scale and directness like those for the entire set of local areas. For this subset, the mode of length (RSLA<15) measures 500–600 feet and captures 26 percent of this subset (Figure 2d). The mode of block area (RSLA<15) measures less than 20 acres and captures 90 percent of this subset (Figure 3c). Of those, the mode measures four to six acres and captures nineteen percent of this subset (Figure 3d). Likewise, the mode of directional distance (RSLA<15) measures 2-3 changes in direction (Figure 2f).

Distinctly different, distance, as measured from the metropolitan centre, is likely affecting the reported mean of metric reach (RSLA). As illustrated for the local areas within 15-miles of the metropolitan centre, the distribution of metric reach (LA) illustrates less skewness (Figure 2e), and the mode is substantially higher. With bins of the histogram distribution set at five miles, the mode of metric reach (RSLA<15) measures 15–20 miles, and it captures 16 percent of this subset.

3.1 COMPARING MEASURES FOR EACH AMERICAN CITY

When measures for these local areas are aggregated for each American city, and the MSA means are examined, distinctions begin to emerge, and a range of measures is established for these American cities. For instance, the MSA mean of length (RSLA) varies from 894.88 feet in New York City to 1790.68 feet in Denver–Boulder (Table 3). Similarly, the MSA mean of block area (RSLA) varies from 66.44 acres in Miami to an extraordinary 231.67 acres in Minneapolis–St. Paul. In terms of the average scale for these local areas, as measured by length and area, New York exhibits the lowest MSA mean of length (RSLA) and one of the lowest MSA means of block area (RSLA) suggesting, on average, local areas with shorter road segments and smaller blocks. Boston, Los Angeles–Riverside–Ventura, and Miami are similar. In contrast, Minneapolis–St. Paul exhibits the highest MSA mean of block area (RSLA) and one of the highest MSA means of length (RSLA) suggesting, on average, local areas with longer road segments and larger blocks. Cleveland – Akron and St. Louis are similar.

In terms of average density, as measured by metric reach, Atlanta and Cincinnati exhibit lower measures, which suggest that their local areas, or neighbourhoods, are lower than average in their density (Table 3), with Denver – Boulder and St. Louis similar. In contrast, Miami and New York City exhibit a higher MSA mean of metric reach (RSLA), suggesting greater densities with Chicago and Los Angeles – Riverside – Ventura similar.

In terms of the configuration, or the directness of road segments within these existing street networks measured by directional distance, Cleveland – Akron demonstrates the lowest MSA mean of directional distance (RSLA), which suggests that road segments within these local areas are more direct in their configuration (Table 3). Chicago, Dallas, Detroit, and unexpectedly, Minneapolis – St. Paul are similar. In contrast, Portland and San Diego demonstrate higher MSA means of directional distance (RSLA), suggesting road segments higher in their circuitousness. Pittsburgh is similar.
### MORPHOLOGICAL CHARACTERISTICS OF THE AMERICAN CITY

A case study benchmarking measures of street connectivity

<table>
<thead>
<tr>
<th>(n) RSLAs</th>
<th>MSA Mean of Length (RSLA) (feet)</th>
<th>MSA Mean of Block Area (RSLA) (acre)</th>
<th>MSA Mean of Metric Reach (RSLA) (miles)</th>
<th>MSA Mean of Directional Distance (RSLA) (changes in direction)</th>
</tr>
</thead>
<tbody>
<tr>
<td>all MSAs</td>
<td>4,321</td>
<td>1382.6562</td>
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<tr>
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<td>152.5512</td>
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<td>90</td>
<td>1145.9438</td>
<td>142.3519</td>
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<td>125</td>
<td>921.0272</td>
<td>81.7104</td>
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</tr>
<tr>
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<td>1516.6831</td>
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<tr>
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<tr>
<td>Detroit</td>
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<td>73.3082</td>
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<tr>
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<td>225</td>
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<td>New York City</td>
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<td>Washington D.C.</td>
<td>166</td>
<td>1176.1295</td>
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<td>8.1887</td>
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</tbody>
</table>

Table 3 - Statistical Measures for the MSA Mean of Length (RSLA), the MSA Mean of Block Area (RSLA), the MSA Mean of Metric Reach (RSLA), and the MSA Mean of Directional Distance (RSLA)
Figure 4 - Illustration of the Distributions of Length (LA) for each American City. Although these distributions are multi-modal, the modal interval consistently measures less than 800 feet, with Cincinnati, Denver-Boulder, Portland as the exceptions.
Figure 5 - Illustration of the Distributions of Block Area (LA) for each American City. Despite differences in geography and planning histories, the modal interval remains consistent, with Atlanta as the exception.
Figure 6 - Illustration of the Distributions for a subset of local areas with measures of Block Area (LA) Less Than 20 Acres for each American City
Figure 7 - Illustration of the Distributions of Metric Reach (LA) for each American City. As with Block Area (LA), the modal interval for Metric Reach (LA) remains consistent across all 24 cities.
Figure 8 - Illustration of the Distributions of Directional Distance (LA) for each American City. Like Length (LA), the modal interval consistently measures less than 6 changes in direction for the captured metric reach, with Pittsburgh and Portland as the exceptions.
In addition to the statistical means, the distributions and frequencies are considered independently for each American city. As an exception for length (LA), Denver–Boulder exhibits a bimodal distribution, with a primary spike at 1,400–1,500 feet and a secondary spike of equal probability at 1,600–1,700 feet (Figure 4) with Cincinnati and Portland similar. For block area (LA), Baltimore, Cincinnati, Cleveland–Akron, Dallas, Denver–Boulder, Detroit, Minneapolis–St. Paul, Philadelphia–Trenton, Phoenix, and Pittsburgh exhibit multimodal distributions (Figure 5), but the modes remain similar, measuring less than 20 acres with the exceptions of Atlanta, Detroit, Minneapolis – St. Paul, and Philadelphia – Trenton. Subsequently, for those local areas measuring, on average, less than 20 acres in block area (LA), the distributions are again multimodal (Figure 6). For instance, Atlanta, Dallas, San Diego and St. Louis exhibit two modes with each capturing equal percentages of the local areas in the random sample. For measures of scale, the distributions are often multimodal, yet the mode remains relatively consistent.

For measures of density and directness, the distributions are consistent between these metropolitan regions, and the modes of metric reach (LA) and directional distance (LA) vary only slightly. Atlanta, Boston, Cleveland–Akron, Detroit, Los Angeles–Riverside–Ventura, Miami, New York City, Philadelphia–Trenton, and Pittsburgh have a mode of metric reach (LA) slightly higher at 5–10 miles than the rest at 0-5 miles (Figure 7). Likewise, the mode of directional distance (LA) remains relatively consistent, with Pittsburgh and Portland as exceptions (Figure 8).

Acknowledged distinctions between these American cities, and their associated measures of scale, density, and directness are captured by the MSA means of length (RSLA), block area (RSLA), metric reach (RSLA), and directional distance (RSLA). And yet despite these distinctions, when measures of the RSLAs are analysed as distributions for each metropolitan area, few differences are demonstrated between their modes, or the interval capturing the measures of those local areas most often encountered. As illustrated, most local areas in these American cities exhibit, on average, higher measures of scale and directness with lower measures of density, regardless of the different planning histories, geographies, and transportation policies influencing them. How then do these local areas of the random sample compare to the historically significant local areas previously studied in the literature?

3.2 BENCHMARKING MEASURES

As already discussed, most RSLAs have an extremely high average of length, block area, and directional distance with a significantly lower average of metric reach. When their measures are benchmarked against previously defined periods of development (Peponis et al., 2007), the scale, density, and directness of existing street networks far exceeds the anticipated range of measures. The mean of length (RSLA) is almost three times as long; the mean of block area (RSLA) is almost four times greater; and the mean of metric reach (RSLA) is less than half than the edge cities previously studied (Table 4).

Explicitly, of the 4,321 RSLAs, 87.7% were even larger in their average length of road segments than the average length reported for previously sampled Edge Cities. For block area (LA), 81.6% were larger in their average area of blocks. For metric reach (LA), 92.5% were less dense in their average metric reach than the Edge Cities, and for directional distance (RSLA), 53.9% were more circuitous.
When measures are benchmarked against noteworthy street networks with distinguishing morphological characteristics (Peponis et al., 2007), like Riverside (Chicago), Levittown (Philadelphia), Radburn (New Jersey), and Reston (Virginia), 82% of these RSLAs measured, on average, more than 600 feet in length, and 62% of the local areas measured, on average, more than 45 acres in block area (Figure 9). With parameters established at 1 mile and 10 degrees, 83% of local areas measured, on average, less than 15 miles in metric reach, and 42% of the local areas measured, on average, more than 5 changes in direction to navigate that captured reach (Figure 10).

As a general characterization of areas within these American cities, most of the RSLAs are longer in their average length, larger in their average block area, sparser in their average metric reach, and more circuitous in their directional distance than even the largest cul-de-sac areas morphologically sampled originally.
Figure 9 - Illustration of the Distributions for Length (LA) and Block Area (LA) in comparison to Influential and Historically Significant Local Areas previously studied within the literature.
Figure 10 - Illustration of the Distributions for Metric Reach (LA) and Directional Distance (LA) in comparison to Influential and Historically Significant Local Areas previously studied within the literature.
4. CONCLUSIONS

The aim of this research was to more adequately depict the morphological characteristics of the American city, examining measures of its scale, density, and directness. Distributions and frequencies were illustrated to both define a more accurate range of measures and determine those encountered most often. Distinctions between the measures of these selected American metropolitan areas were recognized, and lastly, measures of the RSLAs were compared to those noteworthy street networks with distinguishing morphological characteristics for benchmarking purposes.

Acknowledged distinctions between the measures of these American cities are captured by their associated means. Distinctive differences were confirmed by the MSA mean of length (RSLA), block area (RSLA), metric reach (RSLA), and directional distance (RSLA). And yet, when measures were analysed as a distribution, few distinctions were demonstrated between their frequencies. The modes of length (LA), block area (LA), metric reach (LA), and directional distance (LA) were relatively consistent, suggesting then that these American cities share many of the same morphological characteristics of street connectivity, despite their varied planning, economic, geographical, and historical influences. Arguably, this consistency could be capturing the effects of federally mandated policies regulating land subdivision and development across the American landscape, despite different jurisdictions (Ben-Joseph, 2005; Major, 2015).

As a general characterization, the scale, density, and circuitousness of existing street networks in American metropolitan areas far exceeds the anticipated range of measures. Most local areas of the random sample are significantly longer in their average length of road segments, larger in their average area of blocks, sparser in their average metric reach, and more circuitous in their directional distance than even the most sprawling suburban areas originally considered. If the goal of a street network is to fundamentally ‘connect spatially separated places,’ as suggested by Handy et al. (2003), then clearly this study demonstrates that there is much work to be done.
REFERENCES


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ATTRIBUTES OF LOCATION AND HOUSING PRICES IN OSLO:
A monetary valuation with spatial configuration in mind

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ABSTRACT
In this paper, we use a hedonic pricing approach, as defined by Rosen (1974), to estimate the effect of attributes of location on marginal apartment prices in Oslo, Norway, while controlling for structural factors of the apartments. To be able to address urban planners and designers, we aim to use variable specifications that can be interpreted and used in practice, in contrast to area-based measures, simple buffer analyses, or straight line distance measures. This will also allow to test the effect of space syntax measures on housing prices when more precise specifications of attributes of location are used. We conduct different types of accessibility measures with the place syntax tool (PST) using non-aggregated geographical data, including 42,669 apartment sales on address point level, and a hand drawn axial map. An ordinary least square (OLS) model specification is used, and additional statistical analysis to capture patterns in the data to ensure robust results.

It is estimated that spatial configuration has an impact on prices in the apartment market in Oslo, which is in line with previous research in other cities. Most robust is the network integration on radius 30. We can also conclude that access public transit is positively correlated to apartment prices, while private transit is negatively correlated. Access to open water and to the natural reserve Marka is positively correlated with apartment prices.

We believe that we have taken a step further in estimation of hedonic prices due to non-aggregated data and network based measures, and that these additional metric measures even more proves the impact configuration of space has on people’s perception of their surroundings.
KEYWORDS
Hedonic pricing, space syntax, attributes of location, urban design quantification

1. INTRODUCTION

Market values of urban planning and design are usually hard to value, since they cannot be bought or sold. Beyond the construction cost and sales values of buildings and land, very few of the things that urban designers contribute to are ever given a monetary value. Instead, the designs are given other values such as aesthetical, social, and ecological values. Although, these usually are the values sought for in visions, they are rarely given any weight in the city budget, and consequently do not find expression in the implementation of urban development projects. Our study starts from the proposition that if planners can assign monetary value to qualities of urban design, the implementation would follow vision more closely. Given this, it is of high interest to estimate what value urban design creates, whether it is statistically significant or not, and if significant, whether positive or negative.

To manage this task, two problems have to be solved: quantifying urban design and valuing non-market goods. Space syntax methodology possess interesting elements that help solve the challenge of quantifying urban design. If we look at urban design as the placing of destinations and structuring of space, we can interpret it as relations between destinations or between spaces themselves, from here on referred to as attributes of location. Using the axial and segment map as our models of space gives us the opportunity to measure different aspects of spatial configuration (Hillier and Hanson 1989; Hillier 1996). Furthermore, we include destinations in the city to be able to quantify attributes of location connected to the dwellings using the place syntax tool (Ståhle, Marcus, and Karlström 2005). With the axial and segment map as representations of space and with the addition of geocoded destinations in the city, we can quantify the attributes of location to fit the model. This is also a matter of how to subcategorise urban design into precise measures of accessibility and decide which to include or leave out.

The challenge of valuating non-market goods can be solved in two principally different ways, by examining stated or revealed preferences. The stated-preferences approach consists of polls, questionnaires, or experiments to determine willingness-to-pay (WTP) for amenities, while revealed-preferences consists of analysis of actual choices or purchases made (Palmquist 2005). Examples of stated-preference approaches include contingent valuation, multiple price list, choice experiments, experimental auction, and field experiments. This study uses a revealed preference method called hedonic pricing, to estimate marginal WTP. In short, it assumes that the value of a good, in this case, an apartment, is determined by the values of its characteristics, for example, size of the apartment (Rosen 1974). By using regression, a hedonic pricing model estimates the marginal values of each measured characteristic. Because we are using a revealed-preference data set of actual apartment sales, the marginal values are the marginal WTP’s of each characteristic. In most of the studies using this method, the dependent variable is the price of sold dwellings in one or another form.

2. BACKGROUND

Hedonic models commonly work as basis for policy and decision making in city development issues (Whitehead 2012), but usually in fields adjacent to urban design and therefore they do not have a focus on investigating urban design principles. A Norwegian exception is the study of Sjaastad, Hansen, and Medby (2008). Historically, this lack of focus on urban design principles might be explained by lack of computer power or geographical data accessibility.

The theory behind hedonic modelling posits that the housing characteristics used in the model should capture the perceptions of the buyer (see Rosen (1974), Palmquist (2005) and Baranzini et al. (2008)). However, we see a clear gap between what is measured and tested in hedonic modelling and how the same attribute of location is actually perceived. As an example Palmquist (2005) takes pollution, which is very commonly used as a variable in hedonic models but is arguably not really perceived by the consumer. Pollution measured as number of particles in the...
air, has been estimated as negatively correlated to housing prices, but unless it is badly polluted as in some cities in China or India, is impossible for a consumer to perceive small variations in otherwise good air quality. This means that the measure is correlated with what is perceived, but not with what the perception is of. In the same fashion, many attributes of location are measured as objective measures that are hard to link back to consumers’ awareness, which in the end is what the method should estimate. This discrepancy, as we see it, between theory and practice has a lot to gain from space syntax methodology, where the cognition and the human perception of space is a part. Not only can attributes of location be made out of pure space syntax measures, already examined by Chiaradia et al. (2009), Law et al. (2013) and Yang, Orford, and Webster (2016), but also the place syntax methodology can help us be more precise in specifying network measures with attractions closer to how consumers’ perceive it. Only by making the supposition that by measuring attributes of locations through networks that people moves via, we capture how people perceive it to a greater extent and therefore bring new knowledge to the field. In an ongoing systematic review over recent published hedonic studies using accessibility measures in GIS by Heyman, Law & Berghauser Pont (2017), it is shown that there is a broad spectrum of amenities measured but that the specifications of the measures often are quite simple compared to what is preferable to capture perception. Some studies in the grey literature uses the specifications of accessibility measures with a similar approach as we intend in this paper (see Heyman and Manum (2016) for a description of relevant studies).

3. METHOD

This research examines the relationship between apartment prices and attributes of location in the municipality of Oslo in Norway. In this article, we choose to categorise the explanatory variables in the hedonic model into structural and locational variables. The first category refers to characteristics tied to the physical shape and structural measurements of the apartment, and the second category to characteristics tied to the geographical location of the apartment. Thus, locational variables are a set of measured attributes of location. The approach is to use non-aggregated geographical data to perform network based spatial analysis in GIS to measure these attributes of location and furthermore include them in a hedonic model to estimate their individual impact on the marginal apartment price. We first describe the data and sampling procedures and subsequently describe the variable specification and econometric modelling.
3.1 DATA AND SAMPLING

Our data consists of, initially, 42,669 sales of apartments in Oslo between and including 2007 and 2015. The 2007-2015 period is chosen because our locational variables are based on geographical data extracted from within that period. We use the geographical data to proxy quality and quantity of attributes of location in the entire 2007-2015 period, without modification. The sales data was provided by Ambita AS and originally based on two data sets combined. Firstly, the sales reported by realtors to the Norwegian tax agency (Skatteetaten) and secondly, structural characteristics for all apartments in land survey registers (Kartverket). The set included structural characteristics relevant to regression analyses and are connected to the specific apartment and sale price we use as dependent variable.

The resolution of the sales data, is at the address point level, which means a point in space at the entrance of every dwelling. All other geographical data follows that pattern of non-aggregation, apart from socioeconomic data, which we could only retrieve at the level of census tracts. Because we are able to construct non-aggregated and very high-resolution geographical data we can minimize the effect of modifiable areal unit problem (MAUP), described by Unwin (1996).
In our measuring of the attributes of location we used geographical data on a variety of features in the city. Most of the data we obtained from the planning and building agency (Plan- og bygningsetaten, PBE) and the agency of urban environment (Bymiljøetaten) in Oslo municipality. In order to measure the attributes of location we also needed the record of all businesses in Oslo from the Statistics Norway (SSB). From the same source, we retrieved the socioeconomic data on income, employment and education.

The axial map that we used for space syntax analyses was hand drawn and given to us by the consultancy Spacescape in Stockholm and was further developed by us.

We created a set of criteria to remove what we believe were errors in the data: (1) sales for less than NOK 200,000; (2) a price per square meter that is higher than 200,000 NOK/m2; (3) an apartment that is smaller than 10 m2.

3.2 LOCATIONAL VARIABLE DESCRIPTIONS

A general principle has been to use network distance as opposed to straight line distance or area based measures, which corresponds better to how people use and perceive the space. As a ground to start from in the selection and specification of variables, we have looked at previous studies in both Oslo (Sjaastad, Hansen, and Medby 2008; Traaholt 2014) and other Scandinavian capitals (Ståhle and Bernow 2011; Lundhede et al. 2013). As origins in the analyses, we used the sales data, as network we used a hand-drawn axial and segment map of Oslo and as destinations we used matching GIS layers.

For the neighbourhood variable socioeconomic index, we received data on aggregate level but for all locational variables, we followed the example of using non-aggregated data and use network distance to measure accessibility. For all locational variables apart from socioeconomic index, we used the segment map as a network to calculate distances. All measures was made with the place syntax tool (PST) developed at KTH and Spacescape AB in Stockholm and Chalmers University of Technology in Gothenburg.

In general people walk five minutes to make most daily errands (Farr 2007), but it obviously differs by type of errand. This gives a walking distance about 300 meters if one uses the average walking speed of 6 km/h (see Gehl (2011), Gehl and Rogers (2010) and Whyte (2001)). To approximate a neighbourhood reach, we set the network distance to 500 meters, partly to compensate for the assumption that Norwegians are keen walkers, and partly to define a neighbourhood a bit larger than just reaching for the daily errands. Also on the account of radii, we looked at results from previous studies using similar technique and setting (see Ståhle and Bernow (2011) and Lundhede et al. (2013)).

A number of attributes of location are measured as the minimum walking distance to a destination, and even though different specifications have been tested, all benefitted by being treated as logarithmic to compensate for distance decay. The access to highway (WD to Highway Ramp) is specified as the walking distance to any highway ramp. This is to try to capture the effect of car accessibility rather than the noise effect often associated with the actual stretch of the road. A popular destination in Olso is the natural reserve called Marka, it is in fact two different forests, one in the north and one in the south. The variable specification (WD to Marka) is simply the minimum walking distance to either the northern or the southern Marka. Access to open water (WD to Open Water) has been estimated to have a positive effect on housing prices before. In our case, the accessibility to water is specified as the shortest walking distance to a water body with a surface larger than 300,000 m2 or water body with a publicly maintained swimming area. Accessibility to park (WD to Park) is measured as the minimum walking distance to publicly maintained green spaces that are treated as parks by the municipality. The shortest walking distance to a nearest primary school (WD to School) is calculated as well. We collated primary schools that were registered on the municipality’s homepage. Access to public transit was tested in many ways, both with different radii and with different destinations to find the best fit.
Spatial configuration has been measured as network integration on radius 3, 12, and 30 and angular choice on the radius 2, 5, and 10 kilometre walking distance. Radii was chosen to capture both local and global characteristics in the spatial configuration. The analysis was made with PST on a hand drawn axial map, which was converted to a segment map for the choice analyses. The values assigned to every point of sale are from the closest line in space, which was done through the FME software.

Amenity diversity has earlier been shown to have an impact on housing prices in Copenhagen (Lundhede et al. 2013). The aim with the measure is to capture the number of different amenities one can reach within a certain distance, but the ways to define it are numerous. In our case, we have chosen to include shops, restaurants, bars, cinemas, art galleries, museums, and libraries that can be reached within 500 meter walking distance from the apartment. However, just to add them together would give a skew measure in diversity, because of their differences in occurrences in the city; there are many more shops than libraries for example. We try to compensate for this by using equation (1):

\[
\frac{S}{S_{max}} + \frac{R}{R_{max}} + \frac{B}{B_{max}} + \frac{C}{C_{max}} + \frac{A}{A_{max}} + \frac{M}{M_{max}} + \frac{L}{L_{max}}
\]  

The data we used to compile the socioeconomic index variable (Socioeconomic index) was level of employment, education, and income. The two first sets we could find on the smaller level of census tract “grunnkrets” of which there are 540 in the research area, while income was obtained on the even more aggregate level of census tract called “bydel” (16 in the research area). To try to make use of all three variables we disaggregated the information of income on bydeler to census tract (‘grunnkrets’), in order not to lose variation from the other two variables in the index. For employment level, we divided the number of employed with the total number of employable within each census tract in order to get a normalised value. In the same fashion we calculated the share of people with a degree from college or university longer that three years within the age of 20 to 64. Income was measured as average yearly income on bydel and disaggregated down to grunnkrets and normalised according to equation (2). The index was set as the average value (between 0 and 100) from the three components.

\[
z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)}
\]  

All locational variables fitted in the final model are presented in maps in Figure 2 and descriptive statistics in Table 1.
Figure 2 - Maps of locational variables in Oslo municipality included in the final model. All sales are represented as a point in the map and all intervals are set to equal ranges with blue as high values and white as low.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Max</th>
<th>Expected Sign</th>
<th>Mean</th>
<th>Median</th>
<th>Min</th>
</tr>
</thead>
<tbody>
<tr>
<td>log (Per Square Meter Price)</td>
<td>10.56</td>
<td></td>
<td>10.75</td>
<td>10.76</td>
<td>7.17</td>
</tr>
<tr>
<td>Year</td>
<td>±2011</td>
<td>+/-</td>
<td>2011</td>
<td>2007</td>
<td>2015</td>
</tr>
<tr>
<td>log (Apartment Living Area)</td>
<td>5.98</td>
<td>-</td>
<td>4.14</td>
<td>4.14</td>
<td>2.56</td>
</tr>
<tr>
<td>Number of Bathrooms</td>
<td>1.11</td>
<td>+</td>
<td>1.00</td>
<td>1.00</td>
<td>5.00</td>
</tr>
<tr>
<td>Floor Number</td>
<td>3.27</td>
<td>+</td>
<td>3</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>Having Elevator</td>
<td>0.64</td>
<td>+</td>
<td>1.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Network Integration R30</td>
<td>0.57</td>
<td>+</td>
<td>0.60</td>
<td>0.23</td>
<td>0.70</td>
</tr>
<tr>
<td>log (WD6 to Primary School)</td>
<td>7.90</td>
<td>-</td>
<td>6.36</td>
<td>6.43</td>
<td>3.51</td>
</tr>
<tr>
<td>log (WD to Highway Ramp)</td>
<td>8.81</td>
<td>+</td>
<td>7.05</td>
<td>7.12</td>
<td>4.06</td>
</tr>
<tr>
<td>log (WD to Tram)</td>
<td>6.43</td>
<td>-</td>
<td>6.35</td>
<td>2.56</td>
<td>9.26</td>
</tr>
<tr>
<td>log (WD to Marka)</td>
<td>8.07</td>
<td>-</td>
<td>8.28</td>
<td>3.57</td>
<td>8.96</td>
</tr>
<tr>
<td>log (WD to Open Water)</td>
<td>7.46</td>
<td>-</td>
<td>7.73</td>
<td>2.13</td>
<td>8.70</td>
</tr>
<tr>
<td>log (WD to Park)</td>
<td>5.40</td>
<td>-</td>
<td>5.52</td>
<td>2.39</td>
<td>7.41</td>
</tr>
<tr>
<td>Amenity Diversity Index</td>
<td>7.00</td>
<td>+</td>
<td>3.92</td>
<td>0.00</td>
<td>62.07</td>
</tr>
<tr>
<td>Socioeconomic Index</td>
<td>54.19</td>
<td>+</td>
<td>55.57</td>
<td>12.43</td>
<td>85.91</td>
</tr>
</tbody>
</table>

Notes:
1. Expected sign of the coefficient corresponding to a variable.
2. Unit: NOK/m².
3. The year that the apartment was sold.
4. Unit: m².
5. The floor number that an apartment is located.
6. WD stands for walking distance. It is the shortest walking distance, for example, to a nearest primary school.

Table 1 - Descriptive statistics for variables included in the final model.
3.2 ECONOMETRIC APPROACH AND MODEL SPECIFICATION

A number of hedonic price models are estimated based on a stepwise procedure. We begin with an initial model based on structural variables that significantly impacted sales prices of apartments in an earlier study by Traaholt (2014). We test structural variables, the amenity variables, and indexes for multicollinearity, removing variables that have Pearson correlation coefficients higher than 0.7 (Figure 3) or variance inflation factor higher than 4. The model structure is the following:

\[ P_S M P r i c e = \beta_0 + \sum \alpha_i Y_i + \sum \gamma_j S_j + \sum \delta_k A_k + \sum \phi_m I_m + \epsilon, \]  \hspace{1cm} \hspace{1cm} (3)

where \( \beta_0, \alpha_i, \gamma_j, \delta_k, \) and \( \phi_m \) are the coefficients to be estimated, \( Y_i \) are the time relevant variables to capture trending and fluctuation of price in different time (i.e. years of sales), \( S_j \) are the structural variables including for example size of an apartment\(^2\) (i.e. size, floor number, number of bathrooms, and whether having elevator), \( A_k \) are the amenity variables (i.e. the network integration R\(^3\)0, various walking distances), \( I_m \) are the index variables (i.e. amenity diversity index and socioeconomic index), and \( \epsilon \) is the error term. The expected signs of the coefficients are noted in Table 1.

---

1. For example, the number of toilets and the number of bathrooms are highly correlated with a correlation coefficient of 0.74. After testing, we choose to include number of bathrooms.
2. Among the structural variables, we opt to a discrete coding of the effects of floor number to per square meter price because if we were using a continuous coding, we would be assuming that, for example the effect of located in fifth floor was twice as much as the effect of located in the first floor, which would be wrong.
4. RESULTS

The results from the regression are presented in Table 2, which shows the final model's estimations. Although much effort has been made to make the model robust, through testing many different variables and the specification of them, the model explains just under half of the variation in square meter prices among apartments in Oslo and overall it coincides with our expectations and previous studies.

As has been described before, we used dummies for every sales year to capture fluctuations in prices over time, and it is obvious that the prices increases over time with exception for 2008, due to the global recession. Year dummies reveal a negative impact of the 2008 financial crisis on apartment prices relative to 2007. Apartment prices recovered and exceeded their 2007 levels after 2010.

The size of an apartment has a negative effect on square meter price, which has been commonly observed in the market. Toilets and number of rooms in the apartment is highly correlated with number of bathrooms, and the bathroom variables was chosen because it had the highest effect on the explanatory coefficient. Living in higher floors is positively correlated to average per square meter price. With some exceptions, the higher one lives above the ground floor the higher the price. Adjacent to this it is also estimated to be positive if the building has an elevator.

The combined effect of education level, employment level and income level at census tract level is positive on house prices, as expressed by the socioeconomic index. The socioeconomic composition in the neighbourhood is, satisfactory to our expectations, one of the most stable and positive variables explaining apartment prices.

Walking distance to primary schools (WD to School) is negatively correlated to price, which means that a greater distance is considered negative. This is in line with our expectations.

When searching for the effect of accessibility to public transit, we found that walking distance to tram stop (WD to Tram) was the best fit for the model. Testing both for tram, metro, and commuter rail separately and combined, with dummies for different radii and so on, the walking distance to nearest tram stop is the most important determinant for apartment prices in Oslo. Even though walking distance to the nearest tram stop being most prominent factor was a bit surprising, the positive effect of being close to public transit was in line with our expectations.

Walking distance to highway ramps (WD to Highway Ramp) is positively correlated with price, and even though this is expected for access to a disamenity it is suggested, since we are Walking distance to primary schools is negatively correlated to price, which means that a greater distance is considered negative. This is in line with our expectations.

Walking distance to open water is negatively correlated with price, in line with expectations and previous studies (Traaholt 2014; Lundhede et al. 2013; Ståhle and Bernow 2011).

Due to high collinearity between the space syntax measure tested and estimated to have an effect in the model, only one could fit in the final model. Global network integration (Network integration R30) was the most robust of them and had the highest effect on explanatory coefficient. Network integration on radius 12 also had a positive but less stable effect on apartment prices, while radius 3 had a negative but stable effect, when the other two were excluded. Angular choice on radius 2, 5, and 10 kilometres was tested but did not have enough effect on the prices to be included in the final model.

Two of the variables did not turn out as we expected; walking distance to park and amenity diversity, where an increased distance to park is considered positive and a greater diversity of urban amenities within 500 m walking distance is considered negative according to the model.
<table>
<thead>
<tr>
<th>Variable1</th>
<th>Coefficient2</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>11.47****</td>
<td>0.04</td>
</tr>
<tr>
<td>Sold in 20083</td>
<td>-0.02****</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2009</td>
<td>0.01*</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2010</td>
<td>0.06****</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2011</td>
<td>0.14****</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2012</td>
<td>0.20****</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2013</td>
<td>0.26****</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2014</td>
<td>0.30****</td>
<td>0.01</td>
</tr>
<tr>
<td>Sold in 2015</td>
<td>0.40****</td>
<td>0.01</td>
</tr>
<tr>
<td>log (Apartment Living Area4)</td>
<td>-0.28****</td>
<td>0.00</td>
</tr>
<tr>
<td>Number of Bathrooms</td>
<td>0.19****</td>
<td>0.00</td>
</tr>
<tr>
<td>Located on 2nd Floor5</td>
<td>0.04****</td>
<td>0.00</td>
</tr>
<tr>
<td>Located on 3rd Floor</td>
<td>0.06****</td>
<td>0.00</td>
</tr>
<tr>
<td>Located on 4th Floor</td>
<td>0.08****</td>
<td>0.00</td>
</tr>
<tr>
<td>Located on 5th Floor</td>
<td>0.11****</td>
<td>0.00</td>
</tr>
<tr>
<td>Located on 6th Floor</td>
<td>0.13****</td>
<td>0.01</td>
</tr>
<tr>
<td>Located on 7th Floor</td>
<td>0.19****</td>
<td>0.01</td>
</tr>
<tr>
<td>Located on 8th Floor</td>
<td>0.16****</td>
<td>0.01</td>
</tr>
<tr>
<td>Located on 9th Floor</td>
<td>0.17****</td>
<td>0.02</td>
</tr>
<tr>
<td>Located on 10th Floor</td>
<td>0.18****</td>
<td>0.02</td>
</tr>
<tr>
<td>Located on 11th Floor</td>
<td>0.22****</td>
<td>0.02</td>
</tr>
<tr>
<td>Located on 12th Floor</td>
<td>0.21****</td>
<td>0.03</td>
</tr>
<tr>
<td>Having Elevator</td>
<td>0.06****</td>
<td>0.00</td>
</tr>
<tr>
<td>Network Integration R30</td>
<td>0.09****</td>
<td>0.02</td>
</tr>
<tr>
<td>log (Walking Distance6 to Primary School)</td>
<td>-0.01****</td>
<td>0.00</td>
</tr>
<tr>
<td>log (Walking Distance to Highway Ramp)</td>
<td>0.03****</td>
<td>0.00</td>
</tr>
<tr>
<td>log (Walking Distance to Tram)</td>
<td>-0.02****</td>
<td>0.00</td>
</tr>
<tr>
<td>log (Walking Distance to Marka)</td>
<td>-0.02****</td>
<td>0.00</td>
</tr>
<tr>
<td>log (Walking Distance to Open Water)</td>
<td>-0.07****</td>
<td>0.00</td>
</tr>
<tr>
<td>log (Walking Distance to Park)</td>
<td>0.01****</td>
<td>0.00</td>
</tr>
<tr>
<td>Amenity Diversity Index</td>
<td>-0.002****</td>
<td>0.00</td>
</tr>
<tr>
<td>Socioeconomic Index</td>
<td>0.003****</td>
<td>0.00</td>
</tr>
</tbody>
</table>

| Number of Observations | 42,669.00 |
| Adjusted R² | 0.47 |
| AIC | 6,398.23 |
| BIC | 6,684.05 |

Notes:
1 The dependent variable is per square meter sales price of apartments between 2007 and 2015 in Oslo, Norway. The unit is thousand NOK.
2 Coefficient estimates that are statistically significant at 0.001, 0.01, 0.05, and 0.1 levels are marked with ****, ***, **, and *, respectively. Numbers in parentheses are standard errors.
3 The year dummy-variables’ coefficients represent the differences between the per square meter price in 2007 and in that year.
4 Unit: m².
5 The floor number dummy variables’ coefficients represent the differences between located at the ground floor and at the floor that the dummy variable represents, when everything else is the same.
6 By walking distance, we always refer to the shortest walking distance in this table.

Table 2 - Final estimation table from the hedonic modelling.
5. DISCUSSION

Overall, the results show that attributes of location has a great effect on apartment prices in Oslo, and consequently we can show that how we design our cities matter to people’s preferences revealed in the market. The result also suggests that the specifications of these attributes are important for the estimations to be correct, and should be thoroughly investigated. This is also a novelty of this study. We have tried to investigate and develop all measures of location and not only use them as control variables to investigate some other phenomena.

Space syntax measures has been proven influential on housing prices before (Chiaradia et al. 2009; Ståhle and Bernow 2011; Lundhede et al. 2013; Law et al. 2013; Yang, Orford, and Webster 2016). We argue that our study, in addition to the existing literature, proves that even though many other attributes of location is included in the model, the configurational measures, in particular network integration on radius 30, has a robust and with a positive effect on apartment value in Oslo. In other words, when we control for other attributes of location that are often associated with space syntax, we find that space syntax measures are still an important determinant for apartment prices. Due to the collinear nature of the configurational measures, only one could be included in the model, but overall the integration measures proved to have an effect, however, the significance was little or none among the angular choice measures. Our take on this is that the exponential nature of choice values’ distribution over a network does not capture the presumption that an apartment close to shortest paths should give a premium in price.

Since we transfer the space syntax measures’ value from the network to the sales from the nearest neighbour, we see that even though an apartment is close to a route with very high choice values it might be closest to a segment with very low value, a dead end for example. This is not the case for the integration, where the values are more normally distributed over the network. In further research, the transfer of values from the axial or segment map to the points of sales should be considered thoroughly. We would also like to look closer on the effect on prices for apartments located close to a well integrated street but not precisely on it.

We found a small negative effect of the amenity diversity index in Oslo. Examining Copenhagen, Lundhede et al. (2013) found a similar effect, housing prices correlated negatively with amount of restaurants, bars and cafés within 100 m but positively with variety of amenities within 1000 m. This indicate that vibrant urban life including restaurants and cafés very close to the dwelling are not appreciated by residents (supposedly because of noise or other disturbances) but favourable at slightly longer distance. This could be part of the explanation to why diversity of amenities has a negative effect on prices within 500 meter walking distance. We would like to develop this measure and look at alternative radii to see if our expected positive effect can be met. The issue with non-linear correlation of some locational variables is discussed by Heyman and Ståhle (2013) and is a part of on-going research.

The other variable that contradicted our expectations from beforehand was walking distance to park, which we expected to be negatively correlated with prices, but in this model it was positive. In general, closeness to green is considered to be positive, but it also matters what kind of green and how much. As an example (Sjaastad, Hansen, and Medby 2008) found that maintained urban parks and nature had a premium on prices, but green spaces difficult to use, for example between modernistic slab buildings, actually had a negative effect on prices. Based on this, we think that the definition of park in our study should be developed. The definition used now is publicly owned and maintained parks, but this means that there are many more and larger parks outside of the city centre which causes a centre periphery situation. It would be beneficial to define different sizes and even types of parks to see what the effects would be, beside the investigation of the distance between residence and a park.

In further work, it would be beneficial to use data for building height or number of floors. Not least, the variables for which floor the apartment is located at could benefit if it instead could be a continuous variables stating how many floors from the top level it is. We would also be interested in using height data to approximate urban typology (Berghauser Pont and Haupt 2010). This also coincides with our wish to be able to be more accurate with measures for view,
which are not as precise as they could be. However, with building height or number of floors we cannot get the exact location of the apartment and consequently not the exact view, but we will get closer. We could also further investigate the relationship between noise levels, which are modelled at ground level, and the floor level.

We believe that this way of measuring the urban environment in terms of attributes of location, can improve the transmission from the hedonic results to the practice and policy making of urban planners and designers. We will, however, keep investigating more and different locational variables than can contribute to a higher explanatory degree of the model. We will also investigate more advanced specifications of hedonic models to take spatial autocorrelation into consideration.

6. CONCLUSION

It is estimated that spatial configuration has an impact on prices in the apartment market in Oslo, which is in line with previous research in other cities. Most robust is the network integration on radius 30. We can also conclude that access public transit is positively correlated to apartment prices, while private transit is negatively correlated. Access to open water and to the natural reserve Marka is positively correlated with apartment prices.

We believe that we have taken a step further in estimation of hedonic prices due to non-aggregated data and network based measures, and that these additional metric measures even more proves the impact configuration of space has on people’s perception of their surroundings.
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Sjaastad, Morten, Thorbjørn Hansen, and Per Medby. 2008. "Bokvalitet I by Og Etterspurte Bebyggelsetyper.”


ABSTRACT

The research presented in this paper is a case study of intermodal stations of the integrated multimodal transport system implemented in Santiago de Chile, the Transantiago. One of the important innovations of the system is the implementation of a feeder and trunk system that promotes one and sometimes two transfers in a given trip. The fare integration was achieved but the physical integration among modes has been neglected and severely criticized.

The aim of this research was to understand the possibilities that these transfer stations can offer to not only improve the experience of the trip but also, increase the mobility of urban dwellers and provide subcentralities in poor areas with little or no infrastructure and services. For this purpose, three different types of stations were analysed in their urban setting, spatial qualities and use patterns. The results suggest that with proper design and a careful understanding of the city areas and population, a more sustainable transport system can be enhanced improving the quality of life of urban dwellers.

KEYWORDS

Route Choice, Intermodality, Pedestrian Flows, Informal Commerce

1. INTRODUCTION

Though the Underground Metro plays a major role in Santiago’s mobility since it opened in 1972, for decades it was operated as an independent system, and not coordinated with the surface public transport that consisted of an unregulated privately run bus network. It wasn’t until 2007 that both modes were coordinated under the Transantiago, a centralized Metro and bus system. One of the most significant changes in the new system was that it considered a dual system of ‘trunk’ and ‘feeding’ services. The feeding services would collect the local travellers and feed them to the trunk lines, that would cross the city from one end to the other.

This implied, that contrary to the previous system where all lines crossed the whole city competing with each other, the passengers would almost inevitably have to transfer during their journey, once and sometimes twice. The system included intermodal transfer (metro and bus) by incorporating an electronic card with fare integration, yet there was no effective
integration in the actual transfer. Thus the intermodal trip was many times improvised and the transfers were solved in inadequate surroundings with little or no infrastructure. In fact, the Transantiago has been harshly criticized in its implementation and one of the most critical aspects has been precisely this: the transfers.

The governmental answer has been the construction of enclosed, hermetic buildings that offer environmental comfort, some commerce and pedestrian organization during the transfer. These solutions have managed to cut some comfort costs to the traveler (waiting time, walking distance, less uncertainty) but offer little or no additional value to the trip nor to the surroundings of the areas where they are located. In addition, the nodes without a formal intermodal definition, were only required to offer a certain proximity between transport systems—a maximum distance of 200 meters from the Metro access (Moreno, 2009)—giving no importance to the environmental conditions nor the opportunities that the integrated fare system offered.

In brief, the relevant modernization of the transport system with a massive and integrated public transport system was undermined and its full potential has not been developed. We believe that by understanding the intersections as nodes devoid of spatial and territorial characteristics, we are missing the opportunity of generating sub-centralities where passengers could chain activities during their daily trips and the local residents could benefit from commerce and services that previously were unsustainable in the area, as well as to serve as places for interaction and encounter between people. Aiming at this double task—improvement of the daily trips for the travellers and of the commerce and services for the local inhabitants—a study was designed to further understand the possibilities that the required transfer could offer to the users and the city.

Our first intuition suggested that the answer could come from the construction of a ‘place’ rather than a ‘node’ at significant interchange stations. This meant understanding the transfer not merely as an inevitable functional step of the trip, but as a socio spatial opportunity where daily urban needs can be satisfied and social interactions can be carried out. Our first observations had noted that the quality of the transfer was not only about expediency in time and distance, that the possibility of carrying out social, commercial and recreational activities was valued, and that the opportunity for these was many times provided by the informal sector. In sum, the question was: how can place qualities be strengthened in Santiago’s intermodal stations?

2. METHODOLOGY

The study carried out considered systematic observation and modelling of three very different intermodal stations: (i) Escuela Militar, that includes an underground commercial gallery connected to the surface through a sunken square with services and amenities; (ii) La Cisterna, that was solved inside a five story building expressively build for the purpose; (iii) Macul, with no intermodal infrastructure other than Metro accesses and bus stops, but with a strong presence of informal commerce.

In order to understand the urban context of the intermodal nodes, the surrounding area was described and analyzed at three scales: (i) public space use and transport infrastructure (Metro accesses and bus stops) in a 300 m radius; (i) land use in a 500 m radius to the station, including typical location of informal commerce; (iii) configurational properties in an area covering 1500 meter radius.

At the same time, a detailed systematic non-participatory observation study was set out regarding the pedestrian routes and activities carried out in the three stations. In each intermodal station, 100 passengers were followed, without interacting with them, segmented according to the transport mode: 50 passengers arriving in Metro, 25 in bus, and 25 distributed among taxi, car and bicycle. Each track was monitored from the arrival to the node in one transport mode to the boarding of the next transport mode registering all the activities carried out during the transfer, the timing and distance covered.
The data collected considered gender (male, female), age (20 to 40, 40 to 60, or over 60 years old), and activities carried out: banking (cash withdrawal, paying bills), eating (in formal or informal places), groceries (mainly in supermarkets), health (shopping in pharmacies), window shopping (visual interaction with commerce without transaction), leisure (social meetings, rest, contemplation), others (specific commerce such as clothes, electronics or repair shops). Also the physical characteristics of the service when occupied was noted: use of furniture, outdoors or indoors, environmental control, etc.

Time and distance for every path was registered (maximum 500 meters) as well as the time dedicated to each activity (the waiting time for the bus, taxi, or car was not included). The observed routes were classified as Morning Peak (6:00 to 9:00), Midday (12:00 to 15:00) and Afternoon Peak (17:00 to 20:00).

3. TRIPS, TRANSPORT AND MOBILITY

Urban dwellers inevitably need to move through the territory in order to meet (Sheller, 2006; Le Breton, 2006; Urry, 2002); in fact, not even the technological revolution has been able to replace physical movement by virtual communication (Urry, 2002). Probably, in consideration to its relevance, movement —of both people and goods— has remained within the concept of transport, an operative approach to trips. Thus, the subject has been approached emphasizing the economic relation between cost and time: how to achieve the movement from point A to B considering the moving entities as equivalent subjects (Le Breton, 2006). Only from the beginning of the 2000’s sociology, geography and anthropology theorists have proposed to extend the limits of trip study assimilating the social conditions of people, which have different levels of access to movement and hence, opportunities in the urban realm (Gutiérrez, 2012).

Within this framework, access is understood as the ease with which people overcome the distance between two places, and practice their rights as citizens (Miralles and Cebollada, 2003). The rank of the subject’s possible moving differs depending on its spatial environment organization as well as its networks, income, gender role, age, socio-cultural background, etc. Hence, it is no longer relevant ‘how the individual trip habits are’ but ‘how individuals make their identity through their relation with the territory’ (Le Breton, 2006).

From this point of view, mobility itself has been considered a right in its own. Gutiérrez (2012) declares that mobility is about the paths that people make over the territory to concrete everyday needs, and not about getting to places. Mobility is defined as a social performance of movement which combines desires of moving and the capacity to satisfy them. In that event, Urry (2002) claims that a ‘good society’ wouldn’t limit nor prohibit the desire of co-presence, but it would extend the possibilities of co-presence to every social groups. Within this perspective, mobility becomes the aim and transport the means.

The different levels of mobility have been classified according to their reach and capacity. Among these, everyday trips are those made at high frequency and necessary for survival (Kaufmann and Bergman, 2004). Due to the diverse levels of density of urban areas and the different levels of accessibility of its inhabitants, everyday trips are solved with different transport modes (Miralles and Cebollada, 2003): private (mainly cars), public (buses, railways), and non-motorized (cycles and pedestrian). Sustainable mobility promotes the last two categories as they represent advantages in easing congestion, are more energy-efficient and they are equally accessible for people.

In order to take the best advantage of each mode, intermodal transfer has come out as a strategy that allows to combine local means of public transport in suburban areas with massive railway systems that adapt better in central areas for everyday trips. Santiago’s public transport system nowadays operates in this way as it combines the Underground Metro with bus services. The interest of this investigation relies in the space required for the combination of these modes.
4. FROM THE RADIO-CONCENTRIC CITY TO AN INTERMODAL SYSTEM

In 1960, the modernist urbanists of the time proposed the Metropolitan Intercommunal Plan for Santiago (PRIS 1960), which intended to organize a fast growing city with a clear road structure on the ground and a railway public transport system underground (the Metro). The plan considered 15 subcentralities that would alleviate the traditional center and shorten the trips for the population. It is interesting to note that the planned sub-centralities were located at the main road intersections, radius and rings, and not necessarily coincided with Metro stations (see Figure 1). However, in the following years only a few of these subcentralities developed and during two decades only two Metro lines were built, which remained independent from the surface’s transport system, a highly deregulated bus network.

![Figure 1 - Metropolitan Regional Plan for Santiago 1960 (PRIS 1960) with Metro plan superimposed and underlined subcentralities](image)

Although during the 90’s the government made an attempt to regulate the bus system and built a third metro line, it wasn’t until 2007 that Santiago’s public transport was convincingly re-structured, when the railway network was almost duplicated and Transantiago was implemented.

This ambitious integrated public transport plan pretended to rationalize the excessive bus routes by dividing the territory in ten zones attended by local buses (feeder services) which would connect to the Metro and to a metropolitan bus network (trunk services) in segregated roads (BRT) (Figure 2). An integrated fare system was implemented, so that the bus and Metro would be incorporated in one unique payment (Forray and Figueroa, 2012).

This system allowed to universalize the access to intermodal change by reducing the cost of a three-step trip to one price, and so added a million passengers to the million and half that used Metro daily. Nevertheless, the plan started without the necessary buses to run the system nor road infrastructure, and wasn’t able to resolve operational or physical integration effectively (Moreno, 2009). One of the most criticized aspects by the users was precisely the modal shift, as these were carried out under precarious conditions.
Successive governments have since improved the system (lengthening the bus routes, minimizing transfers, building segregated roads and bus stops, adding Metro lines and suburban trains); however, the few built intermodal stations remain without a clear role in the city (Cortés and Figueroa, 2013). In fact, legally they are defined as real estate buildings, which inhibits the possibility to generate sub-centralities.

Nevertheless, this new structural system reactivated some Metro station surroundings attracting movement flows. Figure 3a represents the origin and destiny points in Santiago’s work and study trips, and the passenger card transactions in each bus stop (not including Metro), showing their concentration in the central and eastern cores of the city, which is the richest part of the city.

However, some important bus stop points can be detected in pericentral zones, as those coincide with the passengers shift to the Metro network. In this study we consider these nodes -mainly where radius roads converge with the city’s ring- as potential places to offer the possibility of chaining activities, and thus helping to satisfy the user’s necessities and increasing their mobility range. The three selected cases for the present study can be identified in Figure 3b.
5. INTERMODAL SPACE: NODE AND PLACE

From the transport field point of view, the intermodal space is a node: it represents traffic discontinuities (terminals, bus stops, street intersections and transfer stations), that together with the arcs -continuous traffic segments- make up a transport network. On the other hand, intermodal space can also be understood as a place.

The notion of place, in the social sciences field, has mainly been associated with the western culture concept of Genius Loci: the idea of a desired sensations manifested in the design of affable spaces, which can be related to anywhere in the urban. However, as cities develop and industrialize in the last century, Marc Augé (2004) set this notion in crisis when denouncing the appearance of non-places in the present cities: installations of accelerated traffic of people and goods, transit points, and temporal occupations such as airspace, railways, highways and other means of transport.

The author considers that these spaces are non-identitary -as they deny a collective meaning to those who inhabit them-, non-relational -as they prevent a participative acknowledging-, and non-historic -as they encourage a minimal stability between the space and time references that are common to everyone. Thus Augé defines place as a signified, historic and publicly-referable space.

Nevertheless, other authors differ on how this notion applies to transport nodes. Hannerz (1998) for example states that the constitution of place relies mainly in the street, as it is where habitants become not only city spectators but principal actors of the everyday social life as well. Sheller (2006), on the other hand recognizes in airports -major intermodal spaces- a ‘transition space’ which allows global shrinking to happen and travellers to meet. Contrary to the idea that people coexist or cohabit without living together, the author distinguishes a highly complex social organization where people do activities together in order to make travels happen.

According to Lange (2011) everyday mobility eases the constant transit between different fields of social interaction: (i) the intimate, constituted from the subject in relation with them self and their desires, (ii) the private, made by social bonds of primary character from the most immediate environment, (iii) the communitarian, built from the particular social networks -such
as religious or professional-, and (iv) the public, controlled by the unknown, the individuality and above all anonymity.

The author declares that the juxtaposition of these fields allows ways of ‘hybrid sociability’: in this sense, staying and moving are not selective ways of using urban space, but complementary. Thus urban mobility promotes the configuration of new types of places of sociability between the public and the private. In this manner, place is understood as where private and public social relations happen in a qualified space.

On the other hand, there are several authors that have recognized the importance of carrying out everyday activities as part of their mobility patterns. Le Breton (2006) states that mobility impacts in social life in such a way that society members have gotten used to having a ‘double residence’, when performing every day an activity in somewhere other than home - labour or study, for instance-. However, nowadays many people fulfil more than one activity before or after their everyday destiny, which has lead other authors to refer to some places as ‘anchors’ and obligatory, flexible or optional activities (Stopher et al., 1996).

Primerano (2007) affirms that the optimum method is to consider home as the only ‘anchor’ place, from which the subject moves to perform different activities ‘chained’ in one or more trips. In addition, he declares that chaining is resolved in different manners according to the means of transport used: it is easy to travel to different destinies located in disperse low-density areas in an automobile, while public transport doesn’t allow such path flexibility, but enables to chain activities by foot in high-density areas.

This walkable practice of chaining activities is observed as well in intermodal change, as passengers have to become pedestrians when shifting from one transport mode to another and a relatively significant amount of transactional, social and recreational possibilities are available during the interval. Thus, performing an activity in the intermodal space -although it means a pause in a trip- can increase the subject’s mobility, as it maximizes their access to satisfaction of needs through movement. In order for this to happen, it is necessary that transport nodes develop into mobility places.

6. THE THREE CASES

As shown in Figure 4, the three analyzed cases show very different realities regarding their integration to city’s grid structure and bus system. Figure 4a shows the global integration map of the whole city, identifying the planned sub-centralities and the three analyzed cases over Santiago, and Figures 4b, 4c and 4d show the bus and Metro routes related to each station.

The figures show that from both the perspective of global integration and public transport supply, Escuela Militar works as a public transport hub for the northeast part of Santiago, which the richest part of the city and where most daily destinations are located (as shown in Figure 3). In fact, it can be described as the gateway to the segregated rich residential area. On the contrary, in La Cisterna, the local buses feed the south sector of the city and rarely cross the Vespucio ring barrier. Both of these two cases were planned subcentralities due to their strategic location in the Metropolitan grid structure.

The case of Macul differs from the others as it was not planned as a subcentrality in the 60’s, nor has been formalized as an Intermodal Station and almost all buses are trunk routes. However, although it has less transfers per hour than the other two stations, due to the importance of La Florida axis and the Metro Line 4, 62.000 people shift between transport modes each hour during peak time, compared to 83.000 and 91.000 in the previous cases (MTT, 2015). Therefore Macul station has become an opportunity to be part of the Santiago’s formal Intermodal Stations.

When analyzing the surroundings of each station, differences arise in terms of street structure, land use and public space (see Figure 5).

Escuela Militar station was originally a middle class residential area built under the garden city model, which after the construction of the metro station in the sixties, densified with office and
residential high rise buildings. In an attempt to improve the area’s connectivity, the main road -Apoquindo- was elevated over the city’s ring road -Vespucio- segregating the four quarters of the intersection even further. After several renovations the underground Metro station has managed to integrate the parts, complementing the ground services, and nowadays forms an integral part of the sub centrality serving the area.

In La Cisterna sector the Vespucio ring operates as a sunken highway and the main street -Gran Avenida- absorbs the majority of the integration. Most of the activity is located in this street in small shops, while the inside blocks are mainly residential. The area has very little walkable public space and almost no green area, and most formal intermodal activities are carried out inside the station building, having little or no effect on public space.

Macul station is also in the Vespucio ring road, but here it is an elevated highway. This suburban area is marked with metropolitan axes leaving major sized plots of land occupied with mega supermarkets, furniture outlets or car selling. The radial road La Florida connects the node with poorer residential areas. In terms of occupation, the large scale of the open space discourages pedestrian activity.
Figure 4 - Metropolitan role of the three cases. Global Integration and Public Transportation (FONDECYT Project 1141096 “Densificación e integración social en torno al Metro”)
Figure 5 - Spatial analysis of the three cases
6.1 ESCUELA MILITAR

Although Escuela Militar is not any longer a terminal Metro station, in many senses it still feels as one. It is dominated by car usage with a strong presence of local buses, taxis and picking up which take the travellers to their final destiny. The Vespucio road, with 12 uninterrupted traffic lanes, is impossible to be crossed on ground; but the Metro offers two underground parallel galleries -where the formal commerce is located- that connect the station with the urban context. These open up in four sunken plazas, with services, recreational facilities and connections to taxis and picking up. However, the station itself has no space for buses, which operate on the street system.

The observation of the transfers showed that shifts are faster and shorter during morning and afternoon peak times, than in midday where more activities are carried out. During the morning peak, passengers carry out almost no banking or eating activities, while in the afternoon they carry a more diverse set of them. This is in part due to the opening times of the formal station shops, which open after 9:00 AM, and the lack of informal commerce. Activities carried out by gender and age group also differ: women tend to do more diverse activities while men dedicate to more pragmatic ones (shopping and banking), young people generally stop for eating, and elders use more specific stores (laundry, shoe repair). The elder-women group is the one that leads the usage of supply stores or minimarkets during the afternoon, probably since they fulfil a more traditional role in the domestic sphere.

The shops more intensely used are the two corners located closest to the Metro, these are located in the underground galleries administration, yet have the virtues of open space: greenery, sunlight, open air and direct relation with the city. There is very little informal commerce, primarily because it is not allowed and is surveyed regularly. The external commerce to the station is sometimes used by passengers, but only when it is in the same sidewalk of the bus stop.

From the 100 people followed, 83 were intermodal transfer and 17 were arrivals to Escuela Militar as a destiny, with an average of 185 meters covered and 4.3 minutes of walking. This gives an average of 2.65 km/hr - a speed that might be considered low for a mobility hub- however it is also showing the recurrence of stops carried out by the passengers, and positive conditions for chaining activities. This information is shown in Figure 6, where the observed paths are presented according to gender, age and schedule differences, as well as the average time, distance, and activity ratio of each category.
Figure 6 - Paths and Activities in Escuela Militar
6.2 LA CISTERNA

La Cisterna station receives two Metro lines and 22 bus services in a five story building. The first floor has only shops and fast food restaurants, while in the underground, passengers connect with Metro and wait for buses in a platform surrounded by commerce.

As in Escuela Militar, formal commerce opens mostly after 9:00 am, not attending the morning peak hour passengers. Nevertheless, midday passengers carry out a significant amount of activities -with a 37% of pauses in their transfers- and non transactional activities such as window shopping (mostly middle aged women) and leisure (mostly middle aged men).

A majority of the middle age group carry out one or more activity during their transfer (61% of them paused during their path); while a significant 48% of the elder women group shop for groceries and a 38% of young people carry out eating activities (the last, to the same degree as in Escuela Militar). The most repeated and extended pauses occur in the supermarket and in the outside corners where informal vendors sell coffee and fried food, mostly during winter when the first and last transfers occur, both without daylight.

Transfers represent an 89% of the total observed paths, as could be expected, since the station was designed as a transfer node and the area lacks special destiny attractors (infrastructure, work, study). However, given that a multi-level building was build with the purpose of organizing pedestrian transfers, the average path is surprisingly long -225 meters in average (40 meters more than the previous case) while the amount and duration of activities is similar. This difference might relate to the disperse infrastructure in the open space, where pedestrian routes have been extended in order to accelerate bus and automobile flows.

Moreover, in the open space several practices against regulations were observed: pedestrians skip fences from central road platforms or walk through vehicle-dedicated infrastructure, specially when they can see the access to the intermodal building. In addition, it is noticed that when transferring in the underground platform, passengers tend to walk through the backside of commerce even though it is a place that has less environmental comfort -non acclimatized and exposed to bus gases- only to maintain visual control of the bus. Pedestrian routes are depicted as in the previous case in Figure 7.
Figure 7 - Paths and Activities in La Cisterna
6.3 MACUL

Unlike the other scenarios, the Macul station has no local formal commerce in the area, thus the activities occur as street vendors locate next to the two Metro accesses: the southern access serving Departamental, and the northern access towards La Florida. The majority of the vendors locate themselves under the highway and Metro infrastructure, gathering between the pillars of the flyover, without obstructing pedestrian paths; a few ones locate themselves next to bus stops.

The observations differ considerably to those in the other stations: only 14% of the paths pause with activities, almost solely related to money transactions -transport card charges and cash withdrawal- and buying informal fast food, as well as similar walking distances yet less time spent in transferring: an average speed of 3.88 km/h.

When analyzing the social characteristics of the passengers some patterns repeat: males do more money transactions, young groups concentrate in eating, and elders use other kinds of commerce. Nevertheless, some differences arise: young males are more likely to remain observing and middle-aged females spend more time eating than males.

In regards of time variables, it is noticeable that midday has much less activity than the other stations, as street vendors leave and come back in the afternoon, in which most people carry on transactions and eat less. The most successful hour for vendors is morning peak, when mostly coffee and fried food is sold. As pedestrians trace their paths according to the bus or taxi stops, informal commerce predicts the most intense areas and locates next to the most frequented paths.

Although this is not a formal Intermodal station, 84 out of the 100 tracks observed resulted in transfers. Similarly, to La Cisterna, many paths did not respect regulations, often in acute-angled intersections. Moreover, all the public space below the Highway and Metro lines is not used by pedestrians (regardless of gender, age or schedule, as shown in Figure 8) where no activities are happening and no transport system stops: merely some vehicles park here for free.

The lack of pedestrian activity during transfer can also be related to the large scale of the context, prepared for vehicle movement, which hinders the possibilities of the pedestrian passengers to make transactions or spend leisure time in the open space.
Figure 8 - Paths and Activities in Macul
7. FINAL REMARKS

The most relevant results of the study can be summarized and described at three levels. On the first level, the historical revision of the infrastructure planning and developing of sub centralities in Santiago, reinforced the importance of channelling the public transport flows to activate sub centralities. These have the possibility of attending underdeveloped areas as well as enriching the travelling experience of travelling: the analysis of the three cases shows that it is possible and happens even when the design of the infrastructure or the formal administration schemes (i.e. commerce’s opening hours) are not answering to the demand appropriately. As is typical of Latin American culture, in those cases the informal sector complements the formal, responding to the challenge and providing the required services.

In second place, the exercise showed that urban design can transform a ‘node’ into a ‘place’, thus enriching the social experience of moving in complex urban settings. The next stage should attempt to formalize these efforts in order to create guidelines for the planning and implementation of intermodal stations. Even more, as many authors have stated in recent literature from the social sciences, this could be a relatively cost efficient way of overcoming or at least diminishing the effects of the traditional socio spatial segregation of Latin American cities. In fact, by increasing mobility, allowing chaining and promoting social encounter in transfer places, the poorer population will increase its possibilities of being integrated and thus having access to the advantages offered by a contemporary metropolis.

Third and lastly, a detailed description of the way people move, chain activities and interact during transfer can enlighten us to design better transfer stations and subcentralities in our cities. Gender and age of the passenger are relevant in their use of space, as are the type of activities offered (everyday commerce, banking, groceries combined with leisure space), the environmental conditions (comfort and security) and the visual fields offering information of the coming transport. Leisure activities can also play an important role to activate the node into a place, as well as the connection with greenery or parks.

Furthermore, it was noted that both formal and informal commerce are possible and complementary: as shown in the last case, street vendors by themselves are not able to sustain social encounter, and for formal shops it is difficult to respond in all schedules nor provide direct contact with the bus stops.

Accordingly, open space itself doesn’t encourage activities nor the underground commerce; the most successful place is the one that takes advantages of both: the direct connection with the urban context and environmental qualities of the open (sunlight, fresh air), and the services provided by formal commerce (transaction possibilities, safer perception of the space).

As observed in these stations, the quality of the transfer experience depends, more than in acclimatization or minimizing the paths, in providing well designed pedestrian routes, visual control over buses or the next transport mode, and clear information increasing predictability and feeling of security. Hence a transfer station can use time and distance and still improve the quality of the trip. After all, the city is, above all, a place for encountering the unexpected.
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PHYSICAL SPACE DESIGN FACTORS AFFECTING PEDESTRIAN MOVEMENT ON THE PRECINCT SCALE IN SINGAPORE

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ABSTRACT
This paper investigates design factors that can influence pedestrian movement on the precinct (around eight to ten building blocks within a land plot) scale in Singapore through a comparison between Space Syntax analysis and actual pedestrian movement flows. The hypothesis of this paper is that pedestrian movement is influenced not only by spatial intelligibility as analysed by space syntax but also by numerous physical environmental factors. The main research question addressed in this paper is what environmental factors impact pedestrian movement on the precinct scale. The paper describes research on two recently completed residential developments in Singapore that are of similar scale and residential densities: The Interlace, a private development, and Punggol Waterway Terraces I, a public housing project.

The paper assesses outdoor movement potential through space syntax analysis and actual pedestrian movement as recorded by field observation in these two locations. Differences between the potentials and actual pedestrian movements are presented through comparison. The paper then presents interviews and social surveys that were used to investigate residents’ space perception and space preferences for different activities. Combining this with the physical space quality analysis, the paper then summarizes the factors influencing people’s movement.
KEYWORDS
Singapore, space design, space syntax, pedestrian movement, precinct

1. INTRODUCTION

Pedestrian movements include a wide range of activities, such as travelling, personal recreation, and social activities, which vary in terms of frequency, duration, route, and effort, among other factors. Identifying and evaluating design factors that influence pedestrian movements and route choices are important to prioritise measures and allocate resources to design comfortable, functional, and pedestrian-friendly residential quarters. Space patterns such as urban configurations are a key generator of aggregated patterns of pedestrian movement in urban scale; this phenomenon has been outlined as a generic process, and developed a methodology of space syntax for spatial description and analysis (Hillier, 1996; Hillier & Hanson, 1984; Hillier, Penn, Hanson, Grajewski & Xu, 1993; Penn, Hillier, Banister & Xu, 1998; Peponis, Ross & Rashid, 1997). A large body of research on space syntax has found that spatial configuration correlates with observed movement flow as well as individual wayfinding at both urban scales (Barros, De Silva & Holanda, 2007; Berhie & Haq, 2015; Choi & Koch, 2005; Dawson, 2003; Turner, 2007) and indoor environments (de Arruda Campos, Lemlij & Manning, 2007; Fujitani & Kishimoto, 2012; Heo, Choudhary, Bafna, Hendrich, & Chow, 2009; Hölscher & Brösamle, 2007; Hölscher, Brösamle, & Vrachliotis, 2012). Apart from the spatial configuration, functional properties of urban environments such as density and land uses have also been found to be correlated with pedestrian movements in urban areas (Choi, 2013; Ozer & Kubat, 2007).

Compared to large-scale urban areas, the association between pedestrian movement, space configuration, and physical space design factors has received little scholarly attention at the precinct scale. Precincts in Singapore usually refer to clusters of public housing blocks designed and built as a single area. Comprising averagely eight to ten building blocks, precincts are basic units in the development of Singapore: they group up into neighbourhoods; and around nine neighbourhoods consist of a new town. Pedestrian movement in precincts linking directly building blocks connect through to other means of transportations. They play significant roles in either the first and the last mile of public transportation journeys or footpaths for short-distance trips with a range of purposes. Different from urban networks, pedestrian networks on the precinct scale are always considered and designed as a part of outdoor recreation areas or the landscape. This landscape-oriented network design aims more to provide a pleasant physical environment rather than a nice walk experience, which weakens the considerations about the walkability of precinct-scale walkways as connections within or outside of precincts. Correspondingly, pedestrian movement at the precinct scale differs from that in urban areas and indoor environments. The pedestrian movement in a particular precinct is conducted typically by the people who are familiar with and have built cognitive maps of designated areas and the surrounding neighbourhoods. Instead of freely exploring the environment as strangers, precinct pedestrians are more likely to choose their paths based on their personal preferences such as sidewalk width, existing greenery, and so on. Pedestrians on the precinct scale may have a diversity of motivations. Residents may walk around the precinct for exercises or leisure activities rather than travelling to a particular destination, which weakens the influence of path distance on pedestrian movement. Therefore, precinct-scaled pedestrian movements and route choices tend to be less correlated with space configuration than in urban areas and indoor environments.

Based on the hypothesis that precinct-scaled pedestrian movements are influenced more by physical spatial design factors than spatial configuration, this study intends to answer the question of which physical space design factor(s) effect pedestrian movement and route choices if the spatial configuration does not solely affect pedestrian flows. The study compares observed pedestrian path choices with connectivity and integration analysis of space syntax in two residential precincts in Singapore with the purpose of examining this hypothesis. An on-site interview and survey ensued to collect residents’ route choice preferences as well as their underlying considerations of spatial factors for choosing routes. These included path width, traffics, and greenery around the walkways.
As a “City-in-a-Garden”, Singapore has been developing pedestrian networks from the urban to the precinct scale as an important part of the urban blueprint. Relevant research on walkability has been attracting more and more attention from the Government of Singapore due to its benefits related to public health and sustainability. Creating more pedestrian-friendly neighbourhoods and an enjoyable walking experience has been considered an important basis for sustainable transportation.

The primary goal of this paper is to answer the question which physical space design factor(s) may influence pedestrian movements and route choices if the spatial configuration does not (or not solely) affect pedestrian flows at the precinct scale in Singapore. The study compares the observed pedestrian path choices with connectivity and integration analysis of the space syntax method in two residential precincts in Singapore. This was followed up with on-site interviews and surveys for collecting residents’ route choice preferences as well as their underlying considerations of physical space physical factors for choosing routes.

2. DATASETS AND METHODS

To investigate actual pedestrian movements in precincts, two residential developments in Singapore were selected. They are Punggol Waterway Terraces I, a public housing precinct, and The Interlace, a private condominium precinct (Figure 1).

Figure 1 - Locations of the two selected residential precincts in Singapore

Figure 2 - Overviews of Punggol Waterway Terraces I
Completed in 2015, Punggol Waterway Terraces I (Figure 2) is located in the recently developed Punggol New Town in the northern part of Singapore. The precinct consists of an 18-storey residential building, a car-parking basement, and an eco-deck surrounding two hexagonal courtyards with tropical greenery. It is located adjacent to the Punggol Waterfront Walkway and connected to it through a garden on the ground floor in the north. Facilities surrounding the precinct include a shopping centre and Massive Rapid Transit (MRT) terminal station on the other side of Punggol Walk, and a Light Rapid Transit (LRT) station on Punggol Way.

The Interlace (Figure 4) is located adjacent to the downtown area on the east coast of Singapore. Designed by OMA / Buro Ole Scheeren / RSP and completed in 2013, this precinct is one of the largest and the most ambitious residential developments in Singapore. Typologically, this precinct introduces a stacked system of 6-storey blocks around eight hexagonal courtyards with various programmatic themes. The precinct is located next to two national parks and is isolated by an urban expressway and two main streets. A shuttle bus service is provided to connect the precinct with nearby neighbourhoods and a shopping centre in the Harbourfront area.
Some similarities between these two precincts can be found: they were both completed within the last five years; they both consist of around 1,000 units; they both use hexagons in plan to organise the building blocks and courtyards; they both feature car parking in the basement to avoid interrupting outdoor activities from vehicle transportation; and they are both surrounded by major roads while being connected to nearby national parks.

Meanwhile, there are also considerable differences between the properties. As the site area is smaller than that of The Interlace, Punggol Waterway Terraces I has greater population density and building density. These two precincts also differ in terms of their household backgrounds. According to the policies in Singapore, public housing provided by the government is only offered to Singaporean citizens and permanent residents who have intermediate incomes. The Interlace features private properties and accommodates foreigners and households with high incomes. Furthermore, the facility provision in these two precincts also follows different standards. In addition to the playground and fitness equipment in both precincts, The Interlace provides a number of utilities to its residents, including swimming pools, barbeque pits, tennis courts, multi-purpose playground, etc.

Although the outdoor spaces in these two precincts are located on several levels (basement level, ground level, and podium level), there is no overlapping of outdoor spaces. By adding or revising accesses or connections, the spatial layout was transformed from three to two dimensions for the analysis in Depth Map.

The outdoor spatial layouts of these two precincts were firstly broken into the fewest and longest lines of sight that pass through all possible routes of movement in the axial map (Figure 7) through Space Syntax Depth Map (Turner, 2004). Some parameters were used for measurements, including:

- **Connectivity**: measuring the accessibility of each axial line to neighbouring axial lines by simply counting the number of connections per axial line;
- **Integration**: an important global variable measuring the relationship of each axial line to the whole urban system and the mean depth of each axial line in the network relative to all other lines (Hillier et al., 1993); and
- **Intelligibility**: the degree of correlation between connectivity and global integration values of the axial lines in spatial configuration analysis (Hillier, Burdett, Peponis, & Penn, 1987). It is hypothesised that high intelligibility ensures that the spatial configuration is predictable for pedestrian spatial distribution in urban areas (Hillier, 1999; Penn, 2001).

Apart from axial maps, segment maps were used in the current study, as segment maps divide each axis line at every connection point, making segment maps more feasible to study pedestrian
movement and transport than axial maps do (Turner, 2004). Lee & Seo (2013) examined built environment factors that affect pedestrian flow using space syntax and GIS-based methods. They found that the angular segment model provides a better explanation for the correlation than the traditional axial models. Thus, in this study we analysed these two precincts secondly by angular segment analysis (Figure 8). The parameter used for measurement was Segment Angular Integration, which measured how accessible each space was from all others within the radius by using the least angle measure of distance. This measure represents the movement potential of a street segment (Hillier et al., 2012).

We used non-participant on-site observation to measure the actual pedestrian flows in the two precincts. Thanks to the particular profiles of these two precincts and the shapes of building blocks providing with certain high spots above the ground, we were able to observe most of the sites without following or disturbing people. We observed most of the pedestrian movements and activities on the sites continuously and recorded the pedestrian trajectories in the public and green spaces out of building blocks. As both cases are residential precincts, pedestrians don’t always start or finish their journeys at the edges of the precincts. The ends of the trajectories included the main entrances of the precincts, taxi drop-off/pick-up points, edges of the precincts, elevator lobbies and the doors of functional rooms.

We then counted the pedestrians based on the trajectory records. First, we divided the entire walkable areas of the precincts into spatial segments. Each segment was defined by two intersection nodes where people encounter some options in their paths (Figure 6). Within each spatial segment, people cannot change their directions other than walking forth and back. We counted people walking through the segments (from one intersection node to another one) in either direction. We didn’t use the traditional gate count method here in this study as it could not reflect the pedestrian movements in square-liked areas with several paths heading in various directions. Pedestrian flows in these square-liked areas interwove together, which made it difficult to set up a single conceptual gate line to count pedestrians.
Gehl (2011) classifies outdoor activities into three types—necessary activities, optional activities, and social activities—and states that space qualities influence optional activities more obviously than other activities. Therefore, this observation was conducted on both weekdays and weekends over the span of two weeks, covering the hours between 8:30 am and 19:00 pm in order to concentrate on optional activities rather than necessary activities, such as travelling to school or workplaces during rush hours. Information of observed pedestrian movement, such as walking trajectories, were recorded. Over the course of the entire observation, more than 2,000 walking trips were observed and recorded in Punggol Waterway Terraces I and around 1,000 in The Interlace (Figure 9).

The study then focused on the paths showing the significant difference between space syntax analysis and actual pedestrian flows. Kevin Lynch’s City Image theory (1960) was applied to display and categorise the environmental characteristics of those paths. The paths were divided into segments by intersection nodes. The correlations between space environmental features and actual pedestrian flow were established to understand what and how character categories can influence the number of pedestrians.

Lastly, semi-structured interviews and questionnaire surveys were conducted in order to understand the importance of each factor initially to the route choices by ranking the factors. Participants were selected randomly on site.

By combining the above information, the study addresses the implementation of space syntax analysis at the precinct scale, the environmental factors that can influence pedestrian movement, and the importance of these factors to pedestrians.

3. RESULTS

Figure 7 to Figure 9 show the axial map analysis, angular segment analysis produced by Depth Map, and actual pedestrian flow maps of these two precincts.

Through preliminary visual comparison between these analyses, it is clear that the actual pedestrian flows of The Interlace correspond to both axial map analysis and angular segment analysis well in terms of global integration and segment angular integration respectively. Differences between the axial map analysis and the actual pedestrian flows of Punggol Waterway Terraces I are evident; while the angular segment analysis matches, the actual pedestrian flows well in the central area of the precinct.

Table 1 shows the correlations between global integration and connectivity – intelligibility – in these two precincts calculated by Depth Map. High intelligibility of outdoor spaces in a precinct is likely to indicate a clearer hierarchic spatial structure, which is easier for human cognition based on the space configuration. In The Interlace this structure is apparent from entrances to the main street, to individual courtyards, and to residential blocks or facilities. It was expected that the differences existing in Punggol Waterway Terraces I might be due to the comparatively low intelligibility of the space. Surprisingly, both sites have relatively high intelligibility, and the one of Punggol Waterway Terraces I is even greater than The Interlace, which suggesting that pedestrian movements at the precinct scale cannot be predicted by spatial configuration solely.

<table>
<thead>
<tr>
<th>Sites</th>
<th>Space syntax variable</th>
<th>Space syntax variable</th>
<th>Correlation (Intelligibility)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Punggol Waterway Terraces I</td>
<td>Global Integration (rad=n)</td>
<td>Connectivity</td>
<td>r = 0.806</td>
</tr>
<tr>
<td>The Interlace</td>
<td>Global Integration (rad=n)</td>
<td>Connectivity</td>
<td>r = 0.655</td>
</tr>
</tbody>
</table>

Table 1 - Correlations between integration and connectivity (intelligibility) of Punggol Waterway Terraces I and The Interlace by Depth Map
PHYSICAL SPACE DESIGN FACTORS AFFECTING PEDESTRIAN MOVEMENT ON THE PRECINCT SCALE IN SINGAPORE

Figure 7 - Axial map analysis (global integration) of Punggol Waterway Terraces I (left) and The Interface (right). The colour gradient from red to blue indicates the integration levels of axial lines from high to low.

Figure 8 - Angular segment analysis of Punggol Waterway Terraces I (left) and The Interlace (right). The colour gradient from red to blue indicates the integration levels of axial lines from high to low.

Figure 9 - Actual pedestrian flows by observation in Punggol Waterway Terraces I (left) and The Interlace (right)
Differing from the crisp and clear connectivity of street network or corridors because of clear boundary imposed by façade or walls at the urban scale, walkable (and inter-visible) areas at the precinct scale are usually designed as a part of open spaces, where pedestrians can move in arbitrary directions. As shown in Figure 7 and Figure 8, both the axial maps and the angular segment maps of the two precincts are not as clear as those in urban areas. Thus, it is very challenging, sometimes even impossible, to associate precinct-scaled pedestrian movement with a single axial line as opposed to a bunch of lines. In order to overcome this issue, GIS-based axial lines Figure 10 were used for axial map analysis in this paper, as shown in Figure 10. A Pearson correlation coefficient was computed to assess the relationship between integration and pedestrian flows. There was not significant correction between those two variables, \( r = -0.080, n = 109, p = 0.408 \).

![Figure 10 - GIS-based axial line analysis (global integration), navigation space in Punggol Waterway Terraces I. The colour gradient from red to blue indicates the integration levels of axial lines from high to low.](image)

![Figure 11 - Five selected paths in Punggol Waterway Terraces I](image)
The precinct-scaled outdoor space of Punggol Waterway Terraces I is unique in that it connects directly to a national park, a neighbourhood shopping centre and transportation exchange terminal with abundant greenery. This to some extent increases the number of pedestrians in the northern part. To deal with this issue, we excluded data from this region (n = 5), and another Pearson correlation coefficient was computed to assess the relationship between integration and pedestrian flows. There was significant correction between those two variables, $r = .360$, $n = 104$, $p < 0.001$. This finding indicates that the urban infrastructure nearby largely impact pedestrian movements within a precinct, which shall be further investigated in future studies.

In order to investigate whether other physical space design factors can also influence pedestrian movements and route choices at the precinct scale in Singapore, we analysed the environmental characteristics of the Punggol Waterway Terraces I. Five paths were selected (Figure 11):

- Path 1 along the northern boundary, which was used most frequently in the precinct with average 38 pedestrians per hour;
- Path 2 crossing the precinct in the middle with around 11 pedestrians per hour;
- Path 3 connecting the inside residential blocks and the northern one with average five pedestrians per hour;
- Path 4 as a corridor crossing the precincts under the building structure with around four pedestrians per hour; and
- Path 5 along the southern part of the precinct which was seldom used during observation.

By analysing the space elements on these three paths based on Lynch’s theory, the physical characteristics of these five paths are displayed in Table 2. Based on these features, each environmental factor was categorised and marked from 0 to 4 (Table 3). The segments composing those five paths were then classified into the categories under each factor. The distributions of these segments and their averages of the actual pedestrian flow passing through the segment per hour were presented in Figure 12.

The influences of each environmental factor can be generalised as follows:

- The most significant factors (Significance < 0.001) for pedestrian flows are path surface materials, landmark nearby and mosquitos or harmful insects; and the significant factors (significance < 0.05) are transport mode, path width, shade, path orientation and biodiversity.
- Pedestrians seldom appeared on the mixed path that was designated for both pedestrians and vehicles. People chose to use the paths only for walking or cycling.
- Paths with flat and soft surfaces, such as outdoor wood or decorative tiles were more popular than others.
- More pedestrians used the paths that were less than 4 meters wide.
- Pedestrians used the paths with small angular changes or without any angular change.
- Paths with clear landmarks nearby were used more frequently.
- Paths with good biodiversity, such as birds and butterflies, can attract more people to pass through. While the diversity of trees and other greenery was not a primary concern of the route choices.
<table>
<thead>
<tr>
<th>Path 1</th>
<th>Path 2</th>
<th>Path 3</th>
<th>Path 4</th>
<th>Path 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transport mode</strong></td>
<td>Bicycles and pedestrian</td>
<td>Pedestrian</td>
<td>Bicycles and pedestrian</td>
<td>Pedestrian</td>
</tr>
<tr>
<td><strong>Elevation</strong></td>
<td>No</td>
<td>No</td>
<td>Slopes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Path width</strong></td>
<td>Around 4 meters</td>
<td>Around 2 meters</td>
<td>Around 8 meters</td>
<td>Around 2-4 meters</td>
</tr>
<tr>
<td><strong>Cover</strong></td>
<td>No</td>
<td>No</td>
<td>Partly</td>
<td>Completely covered</td>
</tr>
<tr>
<td><strong>Shade</strong></td>
<td>By trees</td>
<td>No</td>
<td>By buildings</td>
<td>By buildings</td>
</tr>
<tr>
<td><strong>Functional facilities</strong></td>
<td>Fitness corner, playground</td>
<td>Playground</td>
<td>No</td>
<td>Pre-schools</td>
</tr>
<tr>
<td><strong>Path edge</strong></td>
<td>Vegetation</td>
<td>Fences and vegetation</td>
<td>Building structure</td>
<td>Building structure</td>
</tr>
<tr>
<td><strong>Surface material</strong></td>
<td>Concrete, colourful</td>
<td>Outdoor timbers</td>
<td>Concrete, colourful</td>
<td>Concrete, colourful</td>
</tr>
<tr>
<td><strong>Orientation</strong></td>
<td>Direct to shopping centre and MRT station</td>
<td>Linking two main pedestrian entrances</td>
<td>Not clear</td>
<td>Not clear</td>
</tr>
<tr>
<td><strong>Surroundings</strong></td>
<td>Many types of vegetation</td>
<td>Many types of vegetation</td>
<td>Building structure and one type of greenery</td>
<td>No</td>
</tr>
<tr>
<td><strong>Landmark</strong></td>
<td>MRT and shopping centre</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Brightness</strong></td>
<td>Natural and artificial lighting</td>
<td>Natural lighting</td>
<td>Natural lighting</td>
<td>Artificial lighting</td>
</tr>
<tr>
<td><strong>Biodiversity</strong></td>
<td>Birds, butterflies, mosquitos, etc.</td>
<td>Birds and butterflies</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Table 2 - Physical characteristics of the five paths in Punggol Waterway Terraces I
<table>
<thead>
<tr>
<th>No.</th>
<th>Environmental factors</th>
<th>Parameters</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transport mode</td>
<td>Pedestrians only</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrians and cyclists</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrians, cyclists and vehicles</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Elevation means</td>
<td>No elevation</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>By slopes or barrier-free facilities</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>By steps</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Path width</td>
<td>Narrow: less than 2 meters</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Medium: around 2 to 4 meters</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wide: more than 4 meters</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>Covers</td>
<td>Covered completely</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Covered partly</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No cover or shelter</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Shade</td>
<td>With shade of buildings and trees</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With shade of buildings only</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With shade of trees only</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Without any shade</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Functional facilities</td>
<td>Connected to functional facilities</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not connected to functional facilities</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>Path edge</td>
<td>Shaped by building structure</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shaped by fences</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shaped by vegetation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Obscured edges</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>Path surface materials</td>
<td>Outdoor wood</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Outdoor tiles</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Decorated concrete</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regular concrete</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Path orientation</td>
<td>Straight forward</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turning with small angles</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Turning with large angles</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Landmark</td>
<td>With visible landmarks</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Without visible landmarks</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Brightness</td>
<td>Natural light and artificial light</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Artificial light only</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Natural light only</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Diversity of vegetation</td>
<td>With a variety of vegetation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With single type of vegetation</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No vegetation</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Biodiversity</td>
<td>With a diversity of birds or butterflies</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Without any birds and butterflies</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Mosquitos or harmful insects</td>
<td>Without mosquitos and harmful insects</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>With mosquitos and harmful insects</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 3 - Categorization of environmental factors
Figure 12 - Distribution of actual pedestrian flow per hour in order of categories of each environmental factors
### Table 4 - Spearman rank-order correlation coefficient between pedestrian flows and physical environmental factors

<table>
<thead>
<tr>
<th>No.</th>
<th>Environmental factors</th>
<th>Parameters</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Transport mode</td>
<td>0.472**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>2</td>
<td>Elevation means</td>
<td>-0.095</td>
<td>0.543</td>
</tr>
<tr>
<td>3</td>
<td>Path width</td>
<td>0.406**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>4</td>
<td>Covers</td>
<td>0.121</td>
<td>0.439</td>
</tr>
<tr>
<td>5</td>
<td>Shade</td>
<td>-0.305*</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>6</td>
<td>Functional facilities</td>
<td>0.241</td>
<td>0.119</td>
</tr>
<tr>
<td>7</td>
<td>Path edge</td>
<td>-0.234</td>
<td>0.130</td>
</tr>
<tr>
<td>8</td>
<td>Path surface materials</td>
<td>0.583**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>9</td>
<td>Path orientation</td>
<td>0.325*</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>10</td>
<td>Landmark</td>
<td>0.559**</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>11</td>
<td>Brightness</td>
<td>0.024</td>
<td>0.878</td>
</tr>
<tr>
<td>12</td>
<td>Diversity of vegetation</td>
<td>0.235</td>
<td>0.130</td>
</tr>
<tr>
<td>13</td>
<td>Biodiversity</td>
<td>0.458**</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>14</td>
<td>Mosquitos or harmful insects</td>
<td>-0.547**</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

****: Correlation is significant at the 0.01 level. *: Correlation is significant at the 0.05 level.

Table 4 - Spearman rank-order correlation coefficient between pedestrian flows and physical environmental factors

### Figure 13 - Ranks of environmental factors based on survey in Punggol Waterway Terraces I. The lower the grade, the more important the factor is.
Meanwhile, some interesting phenomena were also observed:

- Paths without shade or with only tree shade were more attractive than those with building shade.
- There is a robust correlation ($r=-0.547$, significance $<0.001$) between pedestrian flows and mosquitos and harmful insects.

The importance of the above environmental factors to pedestrians in Punggol Waterway Terraces I was ranked through the onsite survey by residents (Figure 13). It is clear that the environmental factors that concerned pedestrians most are the clear orientation, cover and shade of paths, with mosquitos or harmful insects, and the connection to functional spaces such as playgrounds and fitness corners. People also considered whether or not the path was also used by other transport means, whether or not it was easy and comfortable to walk through (surface materials, the width of the path, brightness and orientation). Well, people considered comparatively less the diversity of the surrounding plants, birds and butterflies.

These rankings helped explain some phenomena related to the path choice in the precinct. For instance, the importance of clear orientation can lead people more to the paths that are partly covered or not at all, or the paths with mosquitos. However, certain conflicts between observation and the surveys appeared. For example, transportation mode, biodiversity, path width and surface materials were ranked much less important than observed in the field study. This might suggest that pedestrians didn’t realise the importance of these environmental factors when they choose the routes or might be partly due to the relatively small survey sample size. We postulate that with a large sample size, the inconsistency between users’ preference of environmental factors and their actual choices will reduce.

4. DISCUSSIONS AND CONCLUSIONS

The goal of this paper is two-fold. First, we aim to investigate whether pedestrian movements at the precinct scale in Singapore can be predicted by spatial configuration based on analysis such as axial map analysis and angular segment analysis. Second, if the space configuration does not (at least not solely) determine pedestrian movements at the precinct scale in Singapore, we aim to present an alternative explanation of pedestrian movements and route choices from the perspective of physical environmental factors.

By space syntax analysis, we found that pedestrian movements and route choices on the precinct scale in Singapore can be partly predicted from space syntax studies. The predictions by angular segment analysis were closer to the actual pedestrian flows than those by axial map analysis in the studied cases, which is consistent to the previous literature. All these findings demonstrate spatial configuration influencing actual pedestrian flows to some extents. However, based on our GIS-based analysis spatial configuration or patterns cannot completely determine actual precinct-scaled pedestrian flows although both studied sites have relatively high intelligibility. This is partly due to the walking motivations of precinct-scaled pedestrians differing from those in the urban scale.

On the other hand, the differences between space syntax analysis and actual pedestrian flows indicate that environmental factors (rather than space configuration alone) play important roles in the underlying process of path choices, in particular on the precinct-scale spaces. Via interviews and surveys, we found that Singaporean’s primary concern when choosing a route within a precinct is clear orientation, cover, shade, connection to functional areas, and whether or not there are mosquitos and harmful insects around the path. It is interesting to notice the differences between people’s conscious concern (the survey results) and subconscious actions (the actual pedestrian flows). This will be further investigated in the future study by a large-scale survey.

With regard to the comparison between the two precincts, it is worth noting the differences at the aspects of household demographic background, facility provision and urban connectivity. These three factors, in some degrees, may also affect the interactions between residents and...
precinct spaces, and furthermore impact the influences of each spatial factor on pedestrian flows. For instance, living in an isolated precinct as The Interlace with plenty of facilities, pedestrians tend to move more within the precinct than frequently transit between the precinct and the outside areas, compared to those pedestrians living in relatively more accessible precincts with fewer facilities as Punggol Waterway Terraces I. They might concern landmark and urban infrastructure less than those people living in relatively open precincts with fewer facilities. This important characteristic of pedestrian movement distinguishes our current research with many other studies on pedestrian flows. Whether and how these demographic background, facility provision and urban connectivity impact the pedestrian movements is a question that requires further study.

we must admit that the current paper primarily focused on one site, Punggol Waterway Terraces I, as there were obvious differences between the axial map analysis and the actual pedestrian flows of Punggol Waterway Terraces I, as shown in Figure 7 and Figure 9. The study is still ongoing with respect to observing pedestrian movement, quantifying difference between space syntax analysis and actual pedestrian flows, and conducting surveys on route choices. With the increasing amount of information and survey responses, the findings may be more precise. Meanwhile, other space syntax analyses such as visibility graph analysis (VGA) will be implemented to study the effect of spatial configuration on pedestrian movements and route choices.

Although limited in case studies, the results in our current study are quite promising as a variety of physical design factors such as path surface materials, landmark, and mosquitoes or harmful insects are found to significantly influence pedestrian flows in precinct-scale space in Singapore. Our findings shed new light on the effects of physical design factors on pedestrian movement and route choices.

ACKNOWLEDGEMENT

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LEARNING FROM STRATEGIC SPATIAL LOCALISATION:
Thriving In The World Of Homogeneity Streetscape

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ABSTRACT

Streets, and particularly their sidewalks, in cities of the rapidly developing countries of the Southeast Asian Region have gradually been wiped clean of socio-economic activities under the banner of modernisation. The prime reason for this modernisation is a preference for the orderliness, cleanliness and safety for both pedestrians and automobiles. This modernisation results in the homogeneity and lifelessness of the streets, which is contrast to the spatio-cultural function of the streets, locally. In general, the local streets are lively and economically important to the neighbourhoods amidst their disorderliness, which leads to the authorities’ agitation. Nevertheless, some local streets have survived this modernisation and continue to thrive with liveliness. To what extent could the study of spatial morphology and socio-economic activities unlock the survival of these lively local streets? And, to what extent could the outcomes offer insightfulness to establish an alternative urban design model steep in cultural heritage and benefit everyday usage instead of the homogeneous one?

Four rapidly developing Southeast Asian Cities (Yangon, Hanoi, Phnom Penh and Vientiane) and some of their local streets were chosen for the study as an initial attempt to try to answer these two questions. Spatial morphology, survey of the city centres, and street’s micro land-use observations were carried out. Selective interviews with street users were also conducted to try to understand the operation of street activities. Some findings are reported in this paper. Relationships between strategic spatial localisation and degrees of liveliness could be established among the four cities. To some extent, they have been influenced by the maximisation of economic opportunity instigated by the surrounding settings. This maximisation is made possible by the spatial operation of the local streets. Thus, there is a possibility to establish an alternative urban design model, at least for these cities, which can maintain their spatio-cultural heritage and simultaneously reflect upon the drive for the modern look.

KEYWORDS
Southeast Asian Cities, Street, Localisation, Urban Design, Yangon, Hanoi, Phnom Penh, Vientiane

1. INTRODUCTION

The transformation of streetscape in the rapidly urbanising cities of Southeast Asian countries is widely concerned among the region’s urban scholars. This is due to a recent and common situation that city authorities have a preference for streetscape modernisation with orderliness and cleanliness instead of the conventional messy streets, particularly those in the historical area, which usually are littered with traffic jam, occupied by vendors on the sidewalks, and commercially and spatially extended from the front of the dense and continuous rows of shop houses. The modernisation preference is more apparent in the newly planned areas at the
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fringes of the city centre. A good example of this is a case of Hanoi, which is due to the lack of resistance from long-term residents and the nature of the urban development itself, forming as an alliance between local government, public sector and private sector (Tran, 2015). In the historical area, the attempt to modernise streetscape has faced with more resistance. But the city authorities have taken a tougher stand, and resistance eventually began to subside. The removal of street vendors in the historical area of Bangkok, which is held as the capital of sidewalk eating, is another good example (BMA, 2014). The prime reason the city authorities provide is to ease the flows, of automobiles driving on the streets and of pedestrians walking along the sidewalks. Sidewalk shopping, loitering and the vendors are the main culprits. Thus, by removing both the streets and streetscape are safer to use and become more pleasant to visit, they have suggested.

As streetscape modernisation is inevitable and the acceptant view that streets in Southeast Asia and their sidewalks have strong socio-cultural values is widely shared, scholars began to offer ideas and alternative urban models from their researches. In their attempt to offer an alternative urban design model of streets in Asia, Mateo-Babiano and Ieda (2007) suggest that the adoption of Western street design standard and practices in Asian cities to function as a distribution network, with a preference for car domination and exclusion of the sidewalk design, lead to a deserted city. This is because the multi-activity space, i.e., the sidewalk prioritised by people through movement and non-movement behaviours and has socio-cultural attachment, is compromised. Although they fell short to offer a concrete alternative urban design model for streets, physically or morphologically, they successfully established the socio-cultural aspects, which are transportation hierarchical measures, pedestrian needs, speeds, culture of street uses and walking preferences, for consideration to the policy and design-guideline setting of the Asian streets. In doing so, the generalisation of streets could be manageable, theoretically.

A more physical model of street and streetscape is offered by Oranratmanee and Sachakul (2014) in their study of 15 streets in Thailand, which were classified as neighbourhood/pedestrian streets and town/city streets and locate in historical areas. The streets were surveyed and recorded for: operating time of retail shops and vendors, street dimensions, number of passer-by in a day, number of shops and vendors, arrangements of streetscape by vendors, fees for the vendor per setting, activities in the streets and operators. They are successful to categorise and establish characteristics of Thai pedestrian streets based on spatial, economic, social and political aspects. Hence, street is a public space with multi-functions and facets; and, urban designer should take into their consideration for these associated characteristics when designing. While Oranratmanee and Sachakul’s study (2014) is highly valuable in terms of understanding the association of streetscapes, street life and some aspects of street operation, question arises whether accessibility, i.e., the way in which any street connect to its surrounding streets, has any role in the successfulness of the streets as public spaces. The implication for urban design would be that by imitating these spatial-economic-social-political characteristics to design as well as operation, a successful public space could be created. A number of Space Syntax researches have shown that this might not be the case.

In short, similar type of researches, which is very rich in social, economic and cultural aspects of Southeast Asian streets and streetscapes, has rarely investigated the issue of accessibility of the successful streets and their relationship with those aspects, for example, Drummond (2000) and Tran (2015). This gives rise to a question and an opportunity for the extent to which Space Syntax as a theory and methodology for morphological study of spatial network and its accessibility can unfold the relationships between the socio-economic successful streets and their spatial morphological characteristics. Given the nature of streetscape modernisation focusing on main and/or new streets, attention has been made on the successful, i.e., lively, local streets, many of which have survived and have more chances to survive streetscape modernisation. To what extent could the study of spatial morphology and socio-economic activities unlock the survival of these lively local streets? And, to what extent could the outcomes offer insightfulness to establish an alternative urban design model steep in cultural heritage and benefit to everyday usage instead of the homogeneous one? Hence, this is to supplement those studies mentioned above.
Theoretical framework of this research is Hillier’s theories of foreground and background network and urban areas (Hillier, 2007; 2009; 2012; Hiller et. al, 2007). Syntactically, there is a dual generic form of the city, in this case based on the morphological segment characteristics. One is a foreground network. Another is a background network. The former links centres of different scales together and is created by the interaction of economic and social factors against the latter which minimises energy for movement. They might be defined as general accessibility. The foreground network is created by the lines most likely to continue in their direction, i.e., being less likely to change angles of connection when continuing their routes and often being long lines. The background network usually is formed by short lines connecting to each other at right angle or near right angles and typically is a numerous cluster of residential areas connecting among them and to the foreground network. With regarding to syntactic measurements, there are basically two measurements measuring two types of movement. ‘Choice’ measures ‘through movement’, which is how likely one will pass through segments on trips within a spatial system. ‘Integration’ measures ‘to movement’, which is how segments most likely to be destinations within a spatial system. The hypothesis here is that the lively local streets act as the centre of the foreground network of the local centre, spatially, functionally, socially and economically. These streets are the cores of the local live centres, i.e., having been occupied by movement dependent uses such as retail and catering (Hillier et. al., 2007). They should, in theory, be the links between the foreground and background network. This means that the micro-distribution of retail and catering can take advantage of the accessibility, which helps facilitate those two movement types and support socio-economic functions of the local areas. This, therefore, might contribute to the streets’ survival from the streetscape modernization.

2. DATASETS AND METHODS

Four rapidly developing Southeast Asian Cities (Yangon, Hanoi, Phnom Penh and Vientiane) and some of their local streets were chosen for this study. Of the ten Southeast Asian countries forming the Association of South East Asian Nations (ASEAN), these four countries are rapidly urbanised at an extreme scale that is fuelled by high GDP growth among the other ASEAN countries, currently. Forecast for average annual percentage change for GDP growth from 2016-2020 of Viet Nam is at 6%, Cambodia and Laos at 7.3% each, and Myanmar at 8.2% (OECD, 2016). In comparison, Thailand has average annual percentage change for GDP growth from 2016-2020 forecast at 2.7% and Singapore at 2.4% (OECD, 2016). Two studies were carried out: morphological and fieldwork studies.

2.1 MORPHOLOGICAL STUDY

The morphological study was carried out through the Space Syntax morphological analysis of the street network. The patterns of street networks of the cities, based on data obtained from Open Street Map and city survey, were first investigated. Then, their findings were analysed to frame a more focusing syntactic study in terms of scale of and studied area, and inform the selection of the streets for fieldwork surveys. Segment analyses were chosen for the syntactic studies at the city and the detailed scale. As the research focuses on the detailed scale, the historical area model and the historical area with back-lane model were chosen as the spatial models to study. The back lanes are sub-streets or alleys, which may or may not be accessible by cars, i.e., only for pedestrianising, bicycling and motorcycling. The importance of these sub-streets will be discussed in the next section.

2.2 FIELD TRIP STUDY

The fieldwork study was made by the street survey. There were 13 surveyed streets, three in each city, but four in Phnom Penh. There were two main criteria for their selection. They are local streets with clear evidence of social functions, for religion, political or personal purposes. They have clear evidence of functions, which constitute to live centres as defined by Hillier (2001) that are retail and catering. These surveys consisted of:
a) Recording changes of the street setting, for example: vendors’ locations, shop/street furniture moving and people activities within the streets. They were carried out on a weekday and three times a day: in the morning, lunch and afternoon;

b) Measuring dimensions of streets and the various settings within the streets. Again, they were carried out on a weekday and three times a day: in the morning, lunch and afternoon;

c) Selective interviewing of street users that are shop sellers/vendors and buyers/passer-by. Some questions are spatial related, for example, where the sellers/buyers live and where the products come from. Some are usage/operational related such as how often they come to the streets, theirs purposes, the ability to change the spatial settings, the ability to initiate the activities and their participation with any activities. In total, 289 people were interviewed, 60 from Hanoi, 72 from Yangon, 106 from Phnom Penh and 25 from Vientiane. Of the total, 147 of them are buyers/passer-by, 19 from Hanoi, 57 from Yangon, 57 from Phnom Penh and 14 from Vientiane. 142 of them are shop sellers/vendors, 42 from Hanoi, 15 from Yangon, 49 from Phnom Penh and 36 from Vientiane.

d) However, movement observation of pedestrian and vehicular densities has not been made for the fieldwork study due to the prohibition from the cities’ authorities.

It should be noted here that findings reported in this paper are not from all of the fieldwork study results. They are selectively presented on the findings of how Space Syntax could initially shed light on the systematic relationships between accessibility and usage of the studied streets. As a result, recommendations for conserving selected types of streets from the streetscape modernisation can be made.

3. RESULTS

3.1 SELF-ORGANISING GRID PATTERNS

The four studied cities are colonial cities. The British planned Yangon, while the French did that for Hanoi, Phnom Penh and Vientiane. Three cities are capital cities, Hanoi, Phnom Penh and Vientiane, and one a former capital, Yangon. They are the political and economic centres of their countries. The morphological study of the city model gave a broad result for all the studied cities. Because of the research’s focus at the areal scale and on the areas being the centre for retail and catering as defined by Hillier, the historical areas of these four cities fit with this focus. They are their cities’ major retail and catering centres. Therefore, the two historical area models, the historical area model and the historical area with back-lane model, are the studied spatial models.

For all the four cities, the patterns of street networks within the historical area and their immediate surrounding areas clearly show evidence of the colonial influences. This can be seen from the orthogonal or quasi-orthogonal grids, from the medium-to-large-scale grids in Hanoi, Phnom Penh and Vientiane and from the small-scale grid in Yangon. These grids had been planned. The planning processes have been noted by many scholars (Logan, 2000; Molyvann, 2003; Clément-Charpentier et. al, 2010; Morley, 2013; Fanchette, 2016).

There are two patterns found: a sub-division of medium-to-large-scale grid and a continuity of small-scale grid (Figure 1). The medium-to-large-scale grids of Hanoi, Phnom Penh and Vientiane are further subdivided by denser network of sub-streets. These sub-streets could be alleys or front/back lanes within neighbourhoods or street blocks. Buildings locating along these sub-streets are accessible through them. Majority of the sub-streets only allows pedestrianising, bicycling and motorcycling. The denser networks of the sub-streets are very pronounced in Hanoi and Phnom Penh and less so in Vientiane. The sub-streets locating within the blocks of Phnom Penh often connect directly to the main streets. This is contrast to Hanoi, where the city sub-streets could continually stretch and connect among themselves at a long distance, until joining with the main streets. Furthermore, the denser grids of the sub-streets of the historical areas of Phnom Penh and Vientiane are of orthogonal or quasi-orthogonal pattern, while that of Hanoi is of organic pattern.
Yangon has none of this sub-division. This could be because the city’s historical areas already have small-scale grid. A preference for small-scale grid in Yangon can also be seen from their existence almost throughout the city areas. There is an exception in the central and the northern area of the city, which has a medium-to-large-scale grid. This is a residential area for the city’s upper income residents, whose houses’ lots are often very large.

Figure 1 - A comparison of the historical areas’ street network patterns of Hanoi, Yangon, Phnom and Vientiane

Sources and data: Open Street Map, personal surveys and http://unstats.un.org/unsd/demographic/products/dyb/dyb2.html

<table>
<thead>
<tr>
<th>City</th>
<th>Hanoi</th>
<th>Yangon</th>
<th>Phnom Penh</th>
<th>Vientiane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>19 sq.km</td>
<td>36 sq.km</td>
<td>13 sq.km</td>
<td>21 sq.km</td>
</tr>
<tr>
<td>Number of segments without back lanes</td>
<td>9,535</td>
<td>5,591</td>
<td>2,593</td>
<td>4,387</td>
</tr>
<tr>
<td>Number of segments with back lanes</td>
<td>15,728</td>
<td>n/a</td>
<td>3,926</td>
<td>4,399</td>
</tr>
<tr>
<td>Max NACH without back lanes</td>
<td>1.5121</td>
<td>1.4734</td>
<td>1.5304</td>
<td>1.4805</td>
</tr>
<tr>
<td>Max NACH with back lanes</td>
<td>1.5346</td>
<td>n/a</td>
<td>1.5636</td>
<td>1.4848</td>
</tr>
<tr>
<td>Mean NACH without back lanes</td>
<td>.8327</td>
<td>.8969</td>
<td>1.0437</td>
<td>.8501</td>
</tr>
<tr>
<td>Mean NACH with back lanes</td>
<td>.7744</td>
<td>n/a</td>
<td>.9773</td>
<td>.8497</td>
</tr>
<tr>
<td>Max NAIN without back lanes</td>
<td>1.3664</td>
<td>1.1387</td>
<td>2.0666</td>
<td>1.1048</td>
</tr>
<tr>
<td>Max NAIN with back lanes</td>
<td>1.4989</td>
<td>n/a</td>
<td>2.0289</td>
<td>1.1096</td>
</tr>
<tr>
<td>Mean NAIN without back lanes</td>
<td>.8804</td>
<td>.8392</td>
<td>1.4631</td>
<td>.7692</td>
</tr>
<tr>
<td>Mean NAIN with back lanes</td>
<td>.9429</td>
<td>n/a</td>
<td>1.4089</td>
<td>.7701</td>
</tr>
</tbody>
</table>

Table 1 - A comparison of some syntactic values of Hanoi’s, Yangon’s, Phnom Penh’s and Vientiane’s historical area street network
The emergence of the sub-streets can be seen as an evidence of self-organising characteristics of the historical area grids, which have adapted to the socio-economic needs and functions. Table 1 shows some comparative figures of the studied areas. However, the syntactic values shown in Table 1 have no significant differences between the two models analysed for each city and between those of the four cities. Overall, the values indicate that the historical area grid of Phnom Penh has the strongest structure among the four, is most likely to have continuous grid patterns and ease of accessibility. The degrees of structural and continuous grid patterns of the other three cities are less different. Hanoi’s historical area grid may have high degree of accessibility, but its grid is frequently interrupted. There are similarities found in Yangon’s and Vientiane’s historical area grids’ values. It could be said that the substantial increase of segments when the sub-streets were included in the analyses could impact very locally so much so that the mean and max values do not reflect their inclusion. If this is the case, the segment maps should illustrate and support the evidence of the self-organising characteristics of the historical area grids by the sub-streets better than the values.

Figure 2 - A comparative NAIN map at radius N of the historical areas with sub-streets of Hanoi (top left), Yangon (top right), Phnom Penh (bottom left) and Vientiane (bottom right)
The segment-analysed maps show that there are some similarities of the city grid pattern as suggested by Hillier (2009): the dual characteristic that accounts for the general accessibility within the city grid. The large-scale grids are the structure of the cities and form their foreground networks. Major live-centre functions of the cities occupy the foreground networks, for example, wholesale markets, shopping centres, banks and offices, and so on. The small-scale grids are residential areas and form the background networks connecting to the foreground network. Figure 2 is a comparative NAIN map at radius N of the historical area model with back lanes of Hanoi (top left), Yangon (top right), Phnom Penh (bottom left) and Vientiane (bottom right).

Figure 3 - A comparative NAIN map at radius N of the historical areas with and without sub-streets of Hanoi and Phnom Penh
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When the historical area with and without the back-lane maps are compared, for example, Hanoi and Phnom Penh, the two cities with distinguished sub-street grid patterns, the self-organising grid characteristics within the historical areas can begin to be established (Figure 3). It is markedly clear that the sub-streets strengthen the accessibility of the main streets within which they are directly or sequentially connected to. This is more apparent from NAIN. Syntactic values of these main streets also noticeably increase. Moreover, the sub-streets themselves form a number of local areas in Hanoi, creating another pattern of the background grid. Within these areas, some of sub-streets are their local spatial centres, while majority of the sub-streets are just very local streets. This might be because the sub-streets have to fill large land areas. As for Phnom Penh, the sub-street impact seen from the maps and the increase in syntactic values of their surrounding main streets are less pronounced than those in Hanoi. The sub-streets in Phnom Penh just compliment the over all accessibility of the main streets of the blocks they subdivide.

These patterns are evidences of self-organising characteristics of the historical area grids. They have adapted to the socio-economic needs and functions. They are the local centres, facilitate movement as the links between the foreground and background grids, and even form the background grids themselves. Furthermore, as the sub-streets tend to be organically developed and have been rarely planned (Molyvann, 2003). They could therefor be called ‘the spatial lassier faire’ for these four cities.

3.2 FOREGROUND NETWORK OF THE LOCAL GRIDS

The study sets to investigate the local streets, which act as the live centre of the neighbourhoods, i.e., the background grids. It proposes that these local streets should have spatial characteristics in term of accessibility, which supports the ways in which they can function as social and economic centres. In addition, for the selected four cities and 13 studied streets, these local streets should be the sub-streets. Figure 4 shows locations of the 13 studied streets in the historical areas of Hanoi, Yangon, Phnom Penh and Vientiane. Figure 5 is an example of street setting records of the four surveyed streets in Phnom Penh, which marked the land-use types of ground floor buildings and vendors and their locations. However the dimensions of occupied spaces are not shown here. Figures 6-9 are maps made from some spatial related answers of the interviews. Table 2 displays the radii of the studied streets that have the highest NACH and NAIN values.

Overall, it was found that there were 61 types of the retail and catering functions for shops, and 42 types for vendors. The number of types ranges from four, the minimum, to 30, the maximum on a studied sub-street. In general, there were 15-20 types found in a sub-street. Similar patterns are also found for the vendors. Given that these studied sub-streets are not long streets, the varieties of the types found suggest that they really are the local live centres. Nevertheless, there is no significant relationship between NACH and NAIN with the number of types and the number of premises, which are non-residential, along the segments as shown in Figure 10. The correlations between NACH and NAIN against movement density should give a clearer picture of the relationships although this is not possible due to the reason mentioned previously.
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Figure 4 - A location map of the 13 studied streets in the historical area of Hanoi (top left), Yangon (top right), Phnom Penh (bottom left) and Vientiane (bottom right)

Figure 5 - An example of street survey records of Phnom Penh's four studied streets
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Figure 6 - A spatial related interview map of Hanoi’s three studied streets
Figure 7 - A spatial related interview map of Yangon’s three studied streets
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Figure 8 - A spatial related interview map of Phnom Penh's four studied streets
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Figure 9 - A spatial related interview map of Vientiane’s three studied streets
<table>
<thead>
<tr>
<th>City</th>
<th>Radii with highest values (m.)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NACH</td>
<td>NAIN</td>
</tr>
<tr>
<td>Hanoi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Yen Thai Lane</td>
<td>R300</td>
<td>R1500</td>
</tr>
<tr>
<td>2. Ngo Ngoc Ha, Doi Can</td>
<td>R800</td>
<td>R2500, R6000</td>
</tr>
<tr>
<td>3. Pham Ngoc Thac</td>
<td>R600</td>
<td>R3000, R5000</td>
</tr>
<tr>
<td>Yangon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. 46th Street</td>
<td>R2000</td>
<td>R700</td>
</tr>
<tr>
<td>2. 21st Street</td>
<td>R1000</td>
<td>R900</td>
</tr>
<tr>
<td>3. 22nd Street</td>
<td>R1500</td>
<td></td>
</tr>
<tr>
<td>Phnom Penh</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. 15th Street</td>
<td>R700</td>
<td>R2000, R5000</td>
</tr>
<tr>
<td>2. Inner Lane between 53rd/63rd Streets</td>
<td>R900</td>
<td>R5000</td>
</tr>
<tr>
<td>3. 131st Street</td>
<td>R900</td>
<td>R2000</td>
</tr>
<tr>
<td>4. White Building’s front Lane</td>
<td>R2000</td>
<td>R2000</td>
</tr>
<tr>
<td>Vientiane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. A street connecting Rue Samsenethai and Rue Sethathirath</td>
<td>R1500</td>
<td>R3000</td>
</tr>
<tr>
<td>2. Rue Francois Ngin</td>
<td>R300</td>
<td>R3000</td>
</tr>
<tr>
<td>3. Hong Kae Street</td>
<td>R1000</td>
<td>R500</td>
</tr>
</tbody>
</table>

Table 2 - A comparison on radii with highest syntactic values of the studied streets in four cities

Figure 10 - Scattergrams showing correlations between NACH and NAIN against types of non-residential premises and against number of non-residential premises on the segments
The key findings here are the approximating distances of buyers/passer-by, obtained from the interviews, and the radii with highest syntactic values (Figures 7), and the tendency to have more local radii for NACH and more global radii for NAIN (Table 2). Majority of the buyers/passer-by lived in the sub-streets. This means that the sub-streets are their local centres. A lot of them visited the sub-streets everyday. If they came from other places, those places tended to approximate the radii with highest syntactic values, notably NAIN radii. Among the four cities, Phnom Penh has the closest approximation. Figure 8 shows that buyers/passer-by who came from outside, represented by blue lines for their trips’ origins and destinations, were more likely to come from the 2000-metre distance, while NAIN radius which has highest syntactic value is at radius 2000m too. This is suggestive to establish that the sub-streets are more likely to be their destinations. However, the approximation cannot be concluded for Vientiane due to the limit number of the buyers/passer-by interviewees.

Their tendency to have more local radii for NACH and more global radii for NAIN could help explain the strategic locations of the sub-streets. Given that these sub-streets are the streets of the background network, in order to be a destination the strategic sub-streets should have two spatial characteristics. One is that they should well connect to the foreground network. Having more global radii for NAIN is an evidence of this accessibility and connection. This spatial characteristic help bring to-movement into the sub-streets. Another is that the strategic sub-streets should help minimise local journey distance. This can be achieved by having the more local NACH radii. The local NACH radii generate local through-movement. The strategic sub-streets therefore line on the shortest routes within the neighbourhoods. For both cases, the retail and catering functions can take advantage of the to- and through-movements generated by the accessibility of the sub-streets from their surroundings. These are their strategic spatial characteristics. And, it could be said that this type of sub-streets form the foreground network of the local grids.

4. CONCLUSIONS

The research set out to apply Space Syntax theories and analytical techniques to spatially and systematically investigate the local streets, which have been created by the self-organising grids within the historical areas of Hanoi, Yangon, Phnom Penh and Vientiane, and are also the local socio-economic centres. It is successful to establish that the local streets are spatially strategic. Their strategic locations help facilitate movements that the socio-economic functions within them can take advantage of. Because of this there are relationships between strategic spatial localisation and degree of liveliness. Furthermore, these local streets form the foreground network of the local grids.

Let’s now come back to the reflection on urban design learning from this research. Because of the importance of these local streets, streetscape modernisation should not be applied to them. By getting rid of those vendors or street-settings that thrive on and serve for movements is the miss of opportunity to maximise the spatial nature of these streets for socio-economic uses and purposes. Hence, the alternative urban design model should start with identifying the streets having strategic locations for the local usage, i.e., being local live centre. Then, the design should support the local streets to function as live centres, rather than undermine them. If the streetscape modernisation will be inevitably applied to main streets in such a way that they will become homogeneous, the survival of these strategic local streets systematically could help maintain the heritage of the city life, as a result make the city less generalised and less boring, at least at the areal scale.

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#72
FINDING AN IDEAL MODEL FOR COMPACT CITIES WITH MULTIPOLe NETWORKS

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ABSTRACT
With diachronic changes in the philosophy surrounding urban planning, Japanese cities seem to have transformed dramatically. However, many conventional rules remain the same and continue to be inherited. Residents may remember the location of the original downtown area and their narratives reveal their city’s history to their descendants, showing that the collective senses cannot be demolished easily. When analysing a city, we may observe some spatial layouts for which we cannot find any rationale from the perspective of mathematical analysis. However, if we read these layouts more carefully and study their background in the evolutionary process, we may find a rationale for them. Some such layouts are caused by the collective senses, and have worked as an implicit norm. This norm, to be defined as an ‘urban kernel’, is an important keyword when reading a city morphologically. However, there seems to have been little discussion to date about Japanese local cities from a morphological perspective.

The purpose of this study is to investigate a contentious issue in Japanese local cities – compact cities with multipole networks – by means of space syntax, and discuss the plausibility of such cities from the viewpoint of urban morphology.

In Japan, a new system of urban planning has been proposed by the government and is spreading rapidly; this new system aims to establish compact cities with multipole networks, rather than the conventional compact city, which contains a single pole. In space syntax analysis, local integration is distributed across multipole networks, while global integration comprises unipolar networks. By using these characteristics in the distribution of numerical values, we examine the urban kernel and explore the ideal form of the compact city with a multipole network.

KEYWORDS
Space syntax, Japanese cities, Compact Cities, Urban Kernel

1. INTRODUCTION
As well as being a practical method in urban planning, space syntax also comprises a philosophical theory as a tool that analyses the urban space in which individuals reside. A city does not merely comprise a shape to satisfy the rationale of efficient mobility derived with numerical targets, but is, rather, an ideal form that embodies culture and people’s lives. In comparing different cities, space syntax is important for extracting a city’s underlying philosophy and ultimate shape.
Space syntax extracts the topological structures of cities, thus rendering them comparable. The comparison is then used to calculate common rules among cities in various cultures, leading to the emergence of their respective points of uniqueness. As Rapoport has pointed out, ‘The forms of primitive and vernacular buildings are less the result of individual desires than of the aims and desires of the unified group for an ideal environment’ (Rapoport 1967, p.47.). Regarding cities, we can observe the desires of a unified group of people in relation to their ideal environment because a city's shape is constituted by the lives of its people. However, the ideal form of a unified group is difficult to analyse without making comparisons with other forms.

Over the past century, there have been various attempts to standardize cities via the powerful flow of modernisation, but they have not yet been consolidated into a single type. In Japan, modernisation began after the country's opening up to foreign nations in 1869. Yet, while Japanese cities were thereafter subject to contemporary urban planning and the country's landscape underwent a striking transformation, its traditional cities and villages were preserved. Change was swift but strengthened with the times, and cities became patchworks of new and old norms. Natural disasters and damage from wartime propelled modernisation forward. In large metropolitan centres such as Tokyo, Kyoto, and Osaka, urban problems arose due to concerns over how to control immigrants from rural areas. To solve these challenges, Japanese planners imported new techniques from Western countries and after practically applying such techniques to large cities, the method was then transferred to rural cities.

Currently, planners are attempting to determine how to shape Japanese cities given the country's declining population. As people move from rural areas to large metropolises, the question remains how to revive local cities, which is a major issue. With an eye on solving this problem, the Japanese government has advised planners to use the concept of compact cities. Over the last twenty years, this notion has been applied to rural cities, but there have been many cases of failure. One of the reasons is that these cities did not consider their urban kernels (to be defined in the latter part of this paper). In this paper, we examine this new design by exploring the idea of the urban kernel as well as space syntax.

Before this examination, we will discuss what the urban kernel is by introducing our previous works. We will then conduct a case study on Minoh City, which is the first city to announce plans for a compact city with a multipole network.

2. THE URBAN KERNEL

2.1 THE AUTONOMIC NERVES THAT FORM A CITY

Japan experiences frequent earthquakes and due to its humidity, crops may rot easily. Therefore, Japanese wooden houses have been rebuilt continuously. As a result, the metabolism of Japan’s urban fabric tends to be relatively high. Just as the cells of the human body die and are reborn, Japanese cities are also constantly rebuilt and formed by implicit norms. We classify this implicit norm as the urban kernel. The word kernel is a technical term used in the domain of IT. To use a computer, we require an operating system such as Windows or Mac OS. The kernel is the core system and basement of these systems. It controls the computer, but we cannot see it and require a user interface to view the work. We may also use the concept of kernel in urban research. Just as a computer’s operating system is updated, modernisation has come to Japanese cities. We may feel that the appearance of the computer has changed, but we do not care much about the function of the kernel. In fact, the kernel’s real function cannot be changed easily: A city comprises the aims and desires of the unified group, and that group has a culture and is tied to its traditions.

Japan enforced its first City Planning Act in 1920, the main purpose of which was to suppress unregulated urban expansion. During this era, people could choose where to live freely for the first time, and tended to seek jobs in big cities, a phenomenon that was occurring globally at that time. Big cities require more land for residential use, so over time, cites expanded and new residential areas were formed.
People began to live in areas where no one had ever lived before. Naturally, the method of urban planning in new areas differed from that in existing areas. However, new locations and old towns remained relevant. Cities function as whole systems, so while old and new towns function independently, urban planners tend to either be bound by old norms, or ignore them because they comprise the urban kernel and are difficult to read clearly. In the past, urban planners did not view cities holistically and thus caused them to dysfunction. Here, we will introduce several cases of urban kernels from our previous research.

2.2 KYOTO: A COLLECTIVE SENSE IN TERMS OF BOUNDARIES

Kyoto is Japan’s former capital, founded in the year 794 AD. Its original shape was a strong grid pattern derived from Chinese philosophy. Although this urban shape only existed in blueprints, the land was divided according to the plan even if some areas were not densely populated.

Japan’s political power was transferred from the emperor to the samurai; however, Kyoto, where the emperor lived, was a city where people fought for power and thus it became a focal point of war. For this reason, it was burnt down many times, and subsequently regenerated.

Rakuchu Rakugai Ohezu (See Fig. 1. Kyoto 1701) illustrates the conditions of Kyoto in 1701. At that time, Kyoto spread from north to south. Although we can see a strong grid, the layout has shifted from the original grid. At the end of the 18th century, Hideyoshi, the most powerful man of that era, implemented new urban planning in Kyoto. He built castle walls in the centre and established a strong boundary between the city’s interior and exterior space. Temples located in the centre were forced to move to the boundary line. As well as temples, important urban settlements were formed around the boundary, as shown in the map (See Fig. 1. Detail). These settlements were called etamura, meaning villages in which people of the eta class lived. The eta comprised a social class of outcasts in the era of Japanese feudalism and were discriminated against based on privilege rights; for example, ordinary citizens could not engage in certain kinds of work, such as the leather industry.
The district in which the eta lived was along Kyoto’s historical boundary. Today, Kyoto’s boundary has expanded and the former eta district now lies inside the city. Although Japanese feudalism no longer exists, discrimination continues, not only toward the people who live there, but also in terms of land. Although the rent in this area is relatively inexpensive and the location is convenient, people in Kyoto do not wish to live there. Thus, while the zone around Kyoto station is excellent in terms of convenience, historical and social reasons have impeded its development. This fact, which is difficult to see from the outside, can be called the urban kernel.

2.3 TAIPEI: URBAN PLANNING BY OCCUPIERS

Taipei, located in Taiwan, is one of Asia’s largest cities and was under Japanese rule from 1895 to 1945. Unlike Kyoto, Taipei was designed in such a way that immigrants from Japan, who were unaware of the local urban kernel, broke taboos that pertained among conventional residents.

Before 1895, Taipei consisted of three villages: Mengjia, Dadaocheng, and Castle. Figure 2 shows their locations. Castle was built by China’s Qing Dynasty, which ruled during that period. Mengjia and Dadaocheng were spontaneous settlements created by immigrants from southern China who first moved to Mengjia. Then, after a century, another group of immigrants moved to Taipei; however, they faced challenges coexisting with the older residents, so they decided to build their own village, Dadaocheng, which is downstream of the Tamsui River (Kuo 1986).

![Figure 2 - Historical map of Taipei in 1897](image-url)
Today, the district in the middle of the three villages is called Ximending, but at the time, it was uninhabited due to the presence of wetlands, and because it served as a buffer zone between two Chinese villages that were in conflict with each other. It was also used as a cemetery for Chinese people. The original settlers of Taipei never resided in this area, but when Japanese colonisation began, Japanese people began to settle there, leading it to become one of the most popular urban centres in Taiwan (See Fig.2). Figure 3 displays the results of the axial analysis of Taipei’s evolutionary process. Regarding the outcomes of local integration, we can see that each village has a ‘crest’, which means that a street has a higher integration value than all the adjacent nodes.

On the other hand, in the global distribution, the crest is aggregated in one place. It is inevitably dependent along the boundary. At the global level, Ximending is the most integrated site. Although Ximending had the most potential for integration, it could not become a metropolitan centre due to the influence of the urban kernel among Chinese people. Before colonisation, people in Taipei held a worldview that functioned like the city’s local layout. When Taipei changed due to modernisation, the concept of ‘global’ emerged. When newcomers crushed the idea of the urban kernel that had pertained among the Chinese residents, the local belief in a barrier faded away.
2.4 TSURUGA: THE URBAN KERNEL AS FORMED BY AN AIR RAID

Tsuruga is a port city in central Japan. At one time, it was an important transport hub and the starting point of the route from Japan to Europe via the Korean Peninsula and Russia. Therefore, before World War II, it had a number of hotels and consular offices, and was densely populated. During World War II, the city experienced an air raid and the central area was burnt down, losing all its functions. To revive this area, Tsuruga became a port for importing coal. Then, once oil replaced coal, Tsuruga’s economic vitality declined and shifted to nuclear power generation, which made the city thrive until 11th March 2011. After the Fukushima Daiichi nuclear disaster, the city’s generator was shut down and the city is now economically stagnant.

Although the downtown commercial zone was compact before the war, the severe devastation from the air raid temporarily shifted trade and business to adjacent sites. For restoration, the government applied a ‘war damage revival plan’ to the burnt area. In this plan, the government needed to set a range and this was set naturally on the burnt area, which then became the new central area of commerce after the war. Daido analysed the restoration process, asserting that ‘the merchants who lived in the burnt block needed to move to another place. This led to distribution in the business district. Within the range of the new commercial area, the centre was established close to the station instead of in the conventional spot’ (Daido 1983).

The air raid significantly impacted Tsuruga. At the time of the war, shopping centres in Japan were used for both residential and commercial purposes. People ran shops on the ground floor of buildings and lived on the upper floors. After the air raid, merchants needed to settle down in the suburbs, and visit shopping malls for their business. As a result, places that had burnt down were rapidly revived and modernized, and became popular.

However, after the 1990s, people no longer travelled to the central area for shopping. During the process of revival, a number of residential towns were developed, the size of the city expanded, and urban sprawl occurred. Urban residents tended to visit large shopping malls in their own cars and as a result, the downtown area saw a severe decline in commerce.

To stimulate the central zone, the city of Tsuruga adopted the Act on Vitalization in City Centers in 2009, which continued until 2015. To implement the Act, the city needed to set a range for the space to be revived, which was almost the same as the range that had been established after the war. Although the size of Tsuruga city differs considerably from its size immediately after the war, the same range of planning was set (See Fig.4). This has happened not only in Tsuruga, but also commonly in local cities that have adopted the Act on Vitalization in City Centers.
Thus, we can see that although the downtown boundary was created accidentally by the air raid overnight, the city made the downtown range the same as it had been 70 years previously. Therefore, we can understand the boundary as an urban kernel.

2.5 BOUNDARIES AS URBAN KERNELS

As mentioned in this chapter, there is a sense in the worldview of a city’s residents that differs from the perspective of a top-down plan. Space syntax reads top-down intention from the morphological standpoint, and expresses it in numerical values; the morphological result then distils the residents’ ritual viewpoints.

Kyoto’s boundary was maintained due to religious sentiments toward the temples and covert discrimination, while foreigners broke Taipei’s early taboos. In the example of Tsuruga, the boundary that was set accidentally by air-raid 70 years previously cannot be forgotten. Thus, we can read the urban kernel in these phenomena.

In the next chapter, we will use this concept to discuss Japan’s current urban problems.

3. CURRENT URBAN PROBLEMS IN LOCAL CITIES

3.1 COMPACT CITIES WITH MULTIPOLE NETWORKS

Today, as Japan experiences a declining population, a new issue has arisen: how to curtail the size of cities. This problem is unprecedented and, in order to solve it, the Japanese government passed the Act on Vitalization in City Centers in 1998, and tried to create an ideal model of the compact city. Based on this Act, local governments have tried to stimulate their central zones by bringing in residents and commercial functions from the suburbs. However, many cities have not succeeded. We have studied these phenomena and concluded that the plans lack the proper concepts regarding how to distribute urban functions in appropriate locations (Kigawa et al. 2013; Kigawa and Seo 2009). In 2014, after a number of failures, the government abandoned the conventional policy (the Revised Act on Special Measures Concerning Urban Reconstruction) and developed a new model (Compact Cities with Multipole Networks). In the conventional model, the central urban area was set as the sole hub.

3.2 THE MODEL

Based on the restoration of city centres promoted by local governments, a city’s central urban area is set up in one zone. The purpose of making cities compact is to promote central urban areas. In many cases, central urban areas were established based on the old zones, which were formed before the 19th century. Major railway stations were built around old sites, and commercial streets developed along with the process of modernisation. Over the past 20 years, in addition to central zones, large-scale shopping malls have been built in the suburbs, as Japan has become a car society. Consequently, ‘conflicts’ between ‘old shopping areas’ in front of stations and ‘large-scale retail stores’ in the suburbs have become an urban problem and have been discussed. This is a typical conflict in local cities.

However, in the new model of the compact city, emphasised by the Revised Act on Special Measures Concerning Urban Reconstruction, suburban-urban areas (such as large-scale retail stores) are included as part of the urban induction zone, which comprises the compact city. This zone is incorporated into the network, which is connected to the ‘centre city district’. In terms of the Act, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has declared that, ‘[T]he act promotes a new model, the compact city, to support residents by considering the structure of the entire city’.
Figure 5 illustrates the model proposed by MLIT. In Japan, over 300 cities are preparing for redesign based on the concept of the new compact city utilising a multipolar network. As shown in the figure, the conventional model of the compact city only has one centre. Nevertheless, a number of urban areas have already formed. To control urban sprawl, the Revised Act on Special Measures Concerning Urban Reconstruction established urban induction zones in metropolitan locales and built up networks in city centres and surrounding urban areas. This concept is called dango-to-kushi, a metaphor that roughly translates to ‘dumpling on a skewer’, with the dumplings representing urban areas and the skewers representing networks.

3.3 PROBLEMS WITH THE MODEL OF THE NEW COMPACT CITY

From our analysis of conventional compact cities, we have found that although such a policy could work well in a certain type of urban centre, the process might not be successful when applied to other metropolises. When local governments executed national policy at the local level, the concept of the compact city was understood differently from the original model (Kigawa and Furuyama 2006).

After many municipalities failed to properly implement the notion of the compact city, the government decided to develop a new idea that could be interpreted differently. Since there is no established clinical method that takes elements such as history and culture into account, and since inhabitants construct a subjective image of their cities, planners should consider creating ideal forms morphologically.

As pointed out by Kamata, an officer of MLIT, ‘The perception that each municipality plans with the goal of [building a] compact city based on a multipole network is widespread. Meanwhile, because public awareness is very strong in relation to describing the urban structure of the base and the transportation axis, and to establish the area according to the conditions indicated by the law and operation guidelines, there is no extraction of the task, target, no story. There are cases in which a city’s necessary functions are not sufficient, and it is necessary to determine what facilities need to be established in order to attract residents’ (Kamata 2016).

In this context, we will explore ways in which morphological thinking can be adapted via space syntax, and what proposals are possible.
4. CASE STUDY

4.1 MINOH

Minoh is a city in northern Osaka Prefecture, with a population of 130,000. This centre contains a forested area and the city is divided between north and south. Our analysis mainly focuses on the south, which is split into three districts: the western part (the oldest), the eastern part (where development has progressed since the monorail was built in 1997), and the central part (which already has a large shopping mall). In Minoh, city planning is already advanced. Two stations are currently planned for the central district. In a time of population decline, growth is predicted to rise in the coming decade (City of Minoh 2016).

Minoh has chosen the west as its target for revitalising the centre. Another two areas are also improving via good railway access from Osaka; there is currently no direct railway access to either of these two respective sections from the western part, meaning that Minoh is divided. Therefore, the city aims to apply the new concept of the compact city to Minoh and it is the first municipality to have officially released a plan to become a compact city with a multipole network.

![Figure 6 - The map of conventional centre of Minoh](image)

4.2 PLANNING FOR COMPACT CITIES WITH MULTIPOLE NETWORKS

Minoh was once a typical rural village in Japan. Due to its proximity to Osaka, its railroad was built relatively early and Minoh developed into a commuter town (City of Minoh 2016).

Figure 6 shows a map of the western part of Minoh in 1923. Several settlements formed spontaneously, and a railway runs through the villages; some stations were built next to the town. In the beginning, the railway was only built in the western part, while the central and eastern parts were rural.

By 1967, in addition to the old settlements, the town had expanded around the stations (see Fig. 6). Some of the expanded sections are planned in a grid-like pattern, and most have a labyrinth-like form, which shows that they overtook the old settlements. In that era, Minoh was known as an excellent suburban residential zone.

From the map of 1997 (Fig. 6), we can see a new town with a strong grid-like pattern. Development occurred rapidly and condominiums were also built in the surrounding area. In 2003, a large shopping mall was erected along the road coming from the direction of central Osaka. This will create a suburban zone with large-scale stores.

While such developments progressed, the decline of existing shopping districts became a major problem. For this reason, Minoh formed zones in the western section to encourage people to visit old-fashioned commercial streets around Minoh station. From 2005, the city applied the Act on Vitalization in City Centers to promote the area; simultaneously, Minoh is planning to adopt the concept of the compact city with a multipole network. Figure 7 shows the network...
proposed by the city, which connects three areas. Although the downtown area was set in the west, the core is in the centre. In the west, there are two urban induction zones, while in the east, two urban induction zones have been proposed; the core is designed to be the hub between them. Here, we can observe a different route from Osaka, which is divided as a city, and connects each of the three districts.

Regarding this plan, Kamioka, the officer of Minoh, wrote, ‘Minoh’s area is not so large, especially in the urban sector. It is a very compact city that spans 4 km from north to south, and 7 km from east to west, but it is narrow. It is not necessary to push for the concentration of one pole, but it is necessary to aim toward developing a town that can be balanced as a whole, while also considering the formation of the town and the characteristics of each area’ (Kamioka 2016).

In terms of stimulating the centre, the western area has been targeted, and in the model of the compact city with a multipole network, the central area has been targeted. Perhaps it is necessary to ensure fairness due to government administration in the region.

4.3 SPATIAL ANALYSES

The results of axial analyses on Minoh are shown in Fig. 8. In the result of Minoh in 1923, we can read strong crests in local. The crests of integration in fact synchronize with the location of stations. In global integration, we can read a strong centre around Minoh station and, in fact, the oldest city centre district was formed around this location.
The distribution of integration in Minoh 1967 predicted the future constitution of the city. Route 171 was planned in 1953 and this road brings a strong centre both in terms of global and local integration. Relatively, the integration of the conventional downtown area was lost.

Due to the analysis in Minoh 2016, we can see that the urban road, route 171, functioned strongly in the southern part of Minoh, which is important because it connects the three areas. However, this road was built in the past to avoid the centre and is not directly adjacent to the former centre. In the east, there are condominiums with a strong grid-like pattern, the integration value is homogeneous, and there is a street formation that does not reveal a clear centre. Due to the effects of this layout, the gravity in the centre has a centre-to-west integration across the entire city.

In addition, we can see that global integration is high in the central area where the shopping mall was built. On the other hand, global integration is relatively low around Minoh station, which was once the centre.

4.4. ANALYSES

The case of Minoh reveals problems common to many regional cities in Japan. At the beginning, the centre of Minoh was established in one area, which can be read from both the viewpoints of spatial analysis and urban kernel. The residents understood the area around Minoh station to be the centre of the city and the image of the city, its urban kernel, was formed around this time. As time passed, many developments were carried out in suburban areas, and the size of the urban area of the city changed. The centre that had matured at the beginning could not be derived as the centre from spatial analysis. Thus, the conventional centre could not be deemed the centre of the city. Nevertheless, this centre was fixed in people's minds, for which reason the city carried out the Act on Vitalization in City Centers with respect to the conventional centre of the city.

The new concept of the compact city could be understood as a vector to strengthen the network, such as route 171 in Minoh. This route does not pass the conventional centre, and therefore this vector weakened the old town. This is relatively far from the purpose of compact cities with multipole networks. It is necessary to incorporate the old town into the network before strengthening the network. In this sense, the plan of Minoh could not satisfy the government's concept, but from another viewpoint, the plan does suggest a relatively new image of the city, released from its urban kernel.
5. CONCLUSION

The model of the compact city with a multipole network has a major purpose in restoring existing downtown areas as the core of older parts of cities. However, this is not the best solution in terms of the conflict between the city centre and the suburbs because the network is strengthened in the suburbs and does not mesh well with the city centre.

As shown in the example of Kyoto, the beliefs of people within the city’s boundary line cannot be totally eradicated. The circumstances today are not like those of Taipei, where people from abroad established a top-down system. Furthermore, even if a top-down system were established, Mengjia and Dadaocheng still exist as distinct cities and are important in terms of immigrants’ identities.

Based on our analysis, we can conclude that urban planning in Japan lacks a morphological perspective. Connecting points does not equal constructing a network. It is necessary to understand the current sizes of cities and to read their functions using spatial analysis. Based on such analysis, further study on urban kernels is necessary. This clinical method is required, and so, we believe that space syntax can contribute greatly to Japanese cities.
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FORMAL ADAPTABILITY
A discussion of morphological changes and their impact on density in low-rise mass housing

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ABSTRACT
Upon building completion, housing value starts diminishing over time. If it fails to fulfil stakeholders’ long-term needs, the building becomes obsolescent. While some housing schemes survive, others do not, being inflexible in changes over time. This paper explores physical adaptability as a design characteristic that other things being equal, adds to long-term viability in urban housing. It addresses the topic by investigating the adaptability of urban form and the impact of physical adaptations on space consumption and density in low-income mass residential developments. It studies urban form, buildings, plots and streets in and for themselves independent of their use. The objective is to understand how the three elements adapt over time and which morphological characteristics determine their capacity to adapt, a property that may contribute to greater socio-spatial sustainability in the built environment.

Taking ‘Cité Ouvrière’ as an example – a working-class housing scheme in Mulhouse (France) – the paper traces its transformation process from its birth till the beginning of 21st century. First, it focuses on the adaptability of the streets using space syntax analysis. Having the local network resisting to changes over time, its degree of adaptability has been subject to three factors: the morphology of blocks, the evolution of the wider city network, and the configurational relation of the two local and global networks.

The second part of the paper discusses the building and plot types of Cité Ouvrière and their bottom-up typo-morphological evolution. Based on empirical and archival data, the study identifies eight ‘mechanisms’ of physical change and examines their impact on the built density using Berghauser Pont and Haupt’s Spacematrix density model at the level of building-plot compounds.

Ultimately, the same model is used to describe the degree of adaptability as a matter of built density for four housing typologies. For buildings and plots, adaptability refers to their ability to accommodate effectively changes in their form over time. In the context of Cité Ouvrière, physical adaptations have transformed an initially uniform garden city into a morphologically heterogeneous and compact urban quarter. Despite the original standardisation, a variety of formal outcomes and typological mutations have emerged as a result of three morphological characteristics inherent in the original design: location within the city, low built intensity and small plot coverage providing surplus open space.
KEYWORDS
adaptability, urban form, mass housing, density, Spacemate

1. RETHINKING HOUSING AS AN EVOLUTIONARY PROCESS

Mass housing for low-income population groups has constituted a major topic of discussion for contemporary cities, being debated as a political instrument to housing the masses, as a commodity traded for money, and as a social obstruction to community formation (Turner, 1979; Wakely, 1988; Pugh, 2001; Perlman, 2004; Simpson, 2013). It is mainly provided through top-down centrally administered processes in which occupants rarely participate. The final designs are repetitive uniform environments with poor infrastructure, which fail to create liveable and sustainable spaces (Angélil and Hehl, 2014). Although architects and urbanists have been pushing for user-centric approaches, most of the times these have stayed limited to participatory processes at an early planning level or computer-aided simplifications without a real understanding of how buildings and lifestyles change with time. Housing is not a static entity, but a dynamic socio-spatial configuration that is affected by time, modes of living and socio-economic change. For this reason, it is worth rethinking mass housing not as a one-off design but as an accumulation of morphological refinements over time.

However, the housing that anticipates future growth, presumes an urban form1 (streets, buildings, plots) that is adaptable enough to accommodate physical changes of shape, volume and configuration resulting from inhabitants’ evolving needs. Most studies on adaptability so far focus on the environmental, economic or engineering aspect of buildings. Legislation, technology, energy consumption, economy and land uses are also important factors to consider when talking about adaptability. But designing buildings to be convertible, flexible, energy efficient or re-usable is different from designing them to be adaptable to physical changes (Psarra et al., 2012). While the above-mentioned factors can ensure buildings to be suitable for adaptation, the capacity of a building to adapt is specific to the design of its urban form and the possibilities this offers.

The paper explores the ways buildings, streets and plots can adapt over time in low-income mass residential developments, and the impact of these formal adaptations on space consumption and built density. First, it reviews relevant literature to understand how scholars have so far defined adaptability in the built environment, showcasing a multiplicity of often-contradictory definitions against which the following study is set. Second, it takes a nineteenth-century working-class settlement in Mulhouse, France as an example, to study the physical adaptations of the urban form over time. The paper analyses configurationally the local street network, whose layout has remained unchanged since its completion. At the same time, it studies the extensive bottom-up adaptations performed on individual building-plot compounds between 1853 and 2000. The research classifies all adaptations into eight ‘mechanisms of change’ and uses the Spacematrix density method introduced by Berghauser Pont and Haupt (2004, 2009) to capture first, the effect of each mechanism on the built density independently of other changes and second, the effect of all mechanisms per four housing types and for two historical dates. Ultimately, it is argued that in this context physical adaptations in the urban form had positive effects on its performance. They enhanced the accessibility of the local street network, intensified the open space consumption at the plot level and increased the compactness of the built form, turning an initially uniform settlement into a formally diverse urban quarter.

So far, space syntax studies have addressed adaptability in relation to changes of land use, socio-economic diversity and resilience as well as physical, functional and social changeability in non-domestic built environments (Griffiths et al 2008; Vaughan et al 2010, 2013; Törmä et al 2017). However, this study adopts a purely morphospatial approach to understand the physical dimension of bottom-up adaptability in urban housing. It provides knowledge on how urban form changes over time, the relation of these changes with the built density while linking the concept of adaptability across the three elements of urban form. The intention, however, is not

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1 Streets, buildings and plots constitute the three fundamental elements of town plan according to Conzen, the founder of the British school of urban morphology (Moudon, 1994).
to present an exhaustive research on adaptability and its overall implications on the future built environment. It would require a far more extensive discussion that extends beyond the limits of this paper. Still, results from this research may inform how architects and urbanists approach the design of mass housing in the future. Issues that address the greater societal challenge of housing sustainability regarding the longevity of buildings are also noted.

2. DEFINING ADAPTABILITY: A SHORT INTRODUCTION

Since the 1970s, scholars have explored the concept of adaptability in various overlapping and contradicting ways, making it almost impossible to agree on a single definition (Habraken, 2008). Table 1 presents a list of 16 ‘definition clusters’ created according to the authors’ understanding and analytical approach. It is a result of bibliographic research, which by no means claims to be comprehensive. However, it demonstrates the diversity in the vocabulary employed to capture the concept of adaptability. The main conclusion is that most clusters link ‘adaptability’ to the idea of change over time of either the form, use or performance (economic, environmental, social) of the built environment.

According to Douglas (2006, p. 14), adaptation includes "any work to a building over and above maintenance to change its capacity, function or performance". The purpose of the adaptation is to improve some or all of these aspects and ensure that the building fits for its users, purpose, the planet and the future (Gorgolewski, 2005). Nonetheless, scholars have offered contradicting definitions regarding the way a system can improve its performance through adaptation. In some cases, adaptability is described as the ability of a system to receive or respond effectively to changes in order to avoid obsolescence. In other cases, an adaptable system is one that resists changes and endures over time. In this sense, the concept identifies with longevity or resilience, expressing the capability of a system to last and perform equally well—if not better—than before. This is similar to what Marshall (2009) calls an ‘evolutionary paradigm’, that is, resiliency to change and persistence through time.

Schmidt III and Austin (2016) add two more critical dimensions to adaptability: time and scale (see also Schmidt III et al., 2010). On the one hand, time refers to the diachronic changes of space, function and built form. Vaughan et al (2013) have argued that any analysis of contemporary urban form without its historical precedents will fail to understand how urban environments emerge and grow. On the other hand, scale refers to both to the level of application and effect of adaptations. The extent to which the different elements of urban form change, are changed by each other and relate to the city whole are important elements to acknowledge when exploring adaptability.

At the level of street network, Vaughan et al (2010) have claimed that “the manner in which the smaller scale grid is knitted into the super-grid helps shape the relation between local places and the entire city, between city parts and wholes and the relationship in turn between society and space” (referencing work by Hillier and Penn, 1996 and Hillier and Vaughan, 2007). While this mainly concerned with distributions of movement and land uses, Koch and Miranda (2013) extended the concept further to include the effect of changes on the building interface and forms of inhabitance.

At the scale of the building-plot compound, changes in individual houses may occur without an idea of a larger pattern to which they may contribute (Kropf, 2001). Particularly in mass housing schemes, individual changes can be substantial due to their transformative aggregate effect (ibid, p. 31) that leads to an emergent pluralism in spatial configurations and built forms. These can be additions, extensions, alterations, upgrades, partial demolitions or any other modifications that takes place during the active use of a house, which once again affect the urban interface and forms of inhabitance. Effectively, each change on one of the parts of the urban form has an impact on the entire system (Carter, 1983).

The term resilience –firstly introduced by Holling in 1973 for natural environments—is widely used today in architectural and urban studies often in conjunction with sustainability.
### Definitions of Adaptability

<table>
<thead>
<tr>
<th>Definitions</th>
<th>Examples</th>
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<tbody>
<tr>
<td>Adjust or modify suit new conditions</td>
<td>Schmidt III et al. 2010; Druet, Liction &amp; Vassal 2012; Organization for Economic Co-Operation and Development 1976; Engel and Browning 2008; Li et al. 2008; Random House 2010;</td>
</tr>
<tr>
<td>Respond (readily) to changing needs of users</td>
<td>Kronenburg 2007; Palani Rajan et al. 2003; Gibb et al. 2007; Wilkinson et al. 2009; Schneider and Till 2005; Carroll et al. 1999; Brewerton and Darton 1997; Westman Nielsen and Ambrose 1990;</td>
</tr>
<tr>
<td>Receive (long-term) changes of use; Reuse, allocate a variety of uses</td>
<td>Leeman et al. 2004; Grouk 1992; Hasenmaur 2005; Schmidt III et al. 2010; Bullen and Love 2010; Department of Environment Heritage (Australia) 2004; Kräger 1981; Li et al. 2008; Griffiths et al. 2008; Vaughan et al. 2013;</td>
</tr>
<tr>
<td>Receive physical changes of configuration</td>
<td>Koch and Miranda 2013; Vaughan et al. 2013;</td>
</tr>
<tr>
<td>Relocate, move location</td>
<td>Canadian Standards, 2006; Schmidt III et al. 2010; Organization for Economic Co-Operation and Development 1976; Ross et al. 2008;</td>
</tr>
<tr>
<td>Accommodate and Anticipate subsequent changes, modifications</td>
<td>OECD. 1976; Canadian Standards, 2006; Graham et al. 2011; Gergökçü 2005;</td>
</tr>
<tr>
<td>Evolve, grow</td>
<td>Brand 1994; Kaza et al. 2007; Bon 1972; Steadman 2015;</td>
</tr>
<tr>
<td>Capable for change (size, use, capacity, function, performance)</td>
<td>Douglas, 2006; Schmidt III et al. 2010; Kräger 1981; Steadman 2015;</td>
</tr>
<tr>
<td>Maximise value through life</td>
<td>Graham 2003; Engel et al. 2008; Ellison et al. 2007; Schmidt III and Austin 2016;</td>
</tr>
<tr>
<td>Undertake (quick) transformations</td>
<td>Junge 2007;</td>
</tr>
<tr>
<td>Avoid decay, obsolescence or demolition; Sustainability</td>
<td>Pearce 2004; Bullen and Love 2010; Brand 1994; Pickard 1996; Cooper 2001; Raliras et al. 2004; Brownley et al. 2005; Kurul 2003; Graham 2008;</td>
</tr>
<tr>
<td>Remain ‘fit’ for purpose</td>
<td>Harper 2001; Friedman 2002; Blakstad, 2001; Ridder et al. 2008; Slaughter 2001; Schmidt III et al. 2010; Terma et al. 2017;</td>
</tr>
</tbody>
</table>

Table 1 - Definition clusters of adaptability reviewed by the authors in the literature building upon the work of Schmidt III et al. (2010)
2.1 EMERGENT BOTTOM-UP MORPHOLOGICAL ADAPTABILITY

The study narrows down the definition of adaptability to the capability of buildings to accommodate effectively exterior formal changes introduced by the inhabitants. The effect is an authorless\(^3\), asynchronous and miscellaneous incremental adaptation of space and form as a result of socio-economic needs and technological advancements over time. At the very core of this incremental growth lies a gradual, yet firm process of if-and-when-needed changes that give inhabitants the sporadic opportunity to improve their everyday environment and enhance its performance. In the meantime, houses get altered with little consistency, yet it is possible for certain patterns to emerge due to some shared reasons such as heritage, legislation, technology, economy, society, aesthetics and architectural fashions (Mansfield and Pinder, 2008; Steadman, 2014).

Implicit in this work is the assumption that emergent bottom-up adaptability instigated by the residents themselves, engages them with the future of their house and their neighbourhood, and therefore, can be considered a design strategy that contributes to social empowerment and spatial sustainability\(^4\). The ability of a form to be adaptable and extend its life capacity encourages inhabitants to invest time, resources and effort to maintain it. From a social point of view, adapting existing housing is less disruptive than building anew since residents avoid being relocated and instead, retain their socio-cultural networks based on spatial proximity (Power, 2008). Especially, people with low levels of mobility, they are more likely to stick with their house and learn how to adapt it themselves. Then, according to Turner (1979 p.93), they are not only ‘passive consumers’ who use housing goods and services, but also ‘active participants’ who vigorously take care of their built environment when resources allow for it. Santo (2012) refers to the empowerment behind those ‘advanced building-users’ who have the freedom and capacity to appropriate and transform their houses on their own way.

3. MAPPING THE EVOLUTION OF THE URBAN FORM

Within this context, the study looks at a nineteenth-century mass factory housing: Cité Ouvrière in Mulhouse in northeast France. It seeks to trace the spatial evolution of the urban form from 1853 till 2000. To do so, it uses configurational analysis for the street network, graphical mapping techniques and quantitative research for the buildings and plots. Methodologically, it begins with a historical mapping of the city’s growth and housing’s development. With the use of space syntax theory and tools (Hillier and Hanson, 1984), it analyses the configurational relationship of the local grid with the entire city network and its immediate surroundings. The model includes 33,789 street segments within a circle of 15km diameter. The measures of segment angular integration (closeness centrality) and choice (betweenness centrality) for local and global radii are used to understand the accessibility potential of the network.

Furthermore, through on-site qualitative research and detailed archival work the study records the physical adaptations of houses and plots in two and three dimensions, and classifies the formal outcomes in eight ‘mechanisms of change’ (term coined by Ross et al. 2008)\(^5\). In an attempt to describe adaptability as a matter of density, it uses the Spacematrix density model (Berghauser Pont and Haupt, 2004) to measure the impact of adaptations on the built density at the level of building-plots.

\(^3\) It is of little interest here whether the changes are considered formal or informal from a legal framework point of view.

\(^4\) Sustainability is here linked to the idea of longevity. This is not to say that a sustainable building is one that lasts forever, but rather one that extends its life capacity and avoids obsolescence or demolition while accepting changes over time. For the purposes of this paper, financial and environmental sustainability are not being discussed. However, evidence show that bottom-up adaptations implemented to sound structures are an environmentally friendly and financially secure approach to upgrade the existing building stock.

\(^5\) According to Ross et al. (2008) any change can be characterised by three elements: the agent, the mechanism and the effect of change.
For the analysis of buildings and plots, density "contains valuable information about urban form and the performance of the built environment" (Berghauser Pont and Haupt, 2009, p. 21). The Spacematrix density method helps explain how the density of urban form changes as a result of bottom-up adaptability. It uses four morphological variables: ground coverage (or ground-space-index GSI), floor space index (FSI), number of floors (L) and open space ratio (OSR). These variables are combined in Spacematrix charts giving every building-plot compound (plan area) a unique spatial 'fingerprint'. The same tool is used to evaluate with the use of density: (1) the evolution of urban housing as a whole; (2) the evolution of different housing typologies; and (3) the effect of each 'mechanism of change' independently of each other.

3.1 THE USE OF DENSITY

Density as a descriptive and prescriptive concept of urban form has been repeatedly disputed because it quantitatively homogenises building types and built forms, while its definitions and measurements vary across contexts (Churchman, 1999). Berghauser Pont and Haupt reviewed existing density measures, such as population and dwelling density, land use intensity (FSI), coverage (GSI), building height and spaciousness (OSR), and showed that there is little or no relation between these and urban form. Using any of these measures alone does not help depict the size, configuration and scale of buildings, plots and streets. The reason being that scientific representations and resolutions of density tend to be generic and simplified, due to wide variations of forms across scales. Furthermore, some measurements do not take into consideration the un-built space (open, water, green or streets). And when they do, not all types are included. Neither is consistency kept among the measurements. Additionally, different built types can affect occupancy possibilities, while different social and cultural practices can dictate changes of occupancy rates without changes in the urban form. Essentially, conventional density measurements hint at certain qualities of urban form, but do not fully convey our perception of it. Yet as Berghauser Pont and Haupt (2009, p. 18) conclude, “the concept of density as such cannot be blamed for [these] explanatory shortcomings; this is caused more by the formulation of specific definitions and their applications”.

Thus, Berghauser Pont and Haupt proposed a comprehensive multi-variable density model that combines some of the conventional measurements (FSI, GSI) and introduces network density (N). Network density describes the amount of network per area unit, focusing on the form of the street system, and compensates for the absence of this variable from precedent density studies. Based on the mutual dependence of the elements within the urban fabric, the new model is more inclusive, differentiates between built types and overcomes issues of scalelessness.

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6 This is a term coined by Berghauser Pont and Haupt to describe the position of each building entry on the Spacemate chart.
7 Density was initially used to describe crammed urban conditions of nineteenth-century city centres leading to high population density, getting associated with poor health conditions and social disorder. This led architects and urbanists of the time to redirect their theories towards lower densities propagating in favour of decentralised urban models such as the Garden City movement. Modernism followed suit with low densities in high-rise tabula rasa developments and suburban spread-overs leading professionals and academics to question the true value of the concept. Since then, density gradually became an integral part of debates regarding the future of the cities shifting from a descriptive tool to a measurement of prescriptive agendas for compactness, livability, walkability, diversity, and sustainability – environmental, economic and social – in the built environment.
8 Average number of people per residential dwelling
4. THE EVOLUTION OF CITE OUVRIERE

Figure 1 - Segment angular analysis of Integration and Choice Radius n (global scale) of the wider area around the city of Mulhouse.
Cité Ouvrière is a 19th century mass factory housing built for the workers of the Dollfus, Mieg & Cie textile factory (DMC) in the city of Mulhouse. Situated in the Alsatian region of east France close to Switzerland and Germany, Mulhouse has experienced a glorious industrial past. As part of this and a series of philanthropist infrastructural projects, Cité Ouvrière was realised by the Société Mulhousienne des Cités Ouvrières (SOMCO) with the aim to provide the workforce with salutary and affordable houses as well as subsidised access to property.

4.1 STREET NETWORK
The scheme was originally built at the north periphery of Mulhouse. Following the city growth, the urban boundaries shifted. While the local layout remained unchanged throughout the years, subsequent expansions of the wider city network encircled the area, making it centrally located within the city. Previous research (Kostourou, 2015) argued that the original morphology and the configurational evolution of the street network have contributed to its 'spatial sustainability' (as defined by Hillier (2009)). Space syntax analysis (Figure 1) highlighted: first, the syntactic integration of Cité’s network at all scales and second, a morphologically distinct grid with small and dense blocks that minimise metric distances between any two points. From a functional point of view, this intensified morphology can generate more intimate social encounters between inhabitants-inhabitants and inhabitants-strangers. Moreover, results from the same study using segment angular analysis for integration and choice measures for consecutive metric radii (200, 400, 800, 1200, 2400 and n) showed that the neighbourhood is metrically integrated at local scales and surrounded by streets of high choice value at the global scale. The peripheral and main streets are likely to receive higher pedestrian movement flow and attract more non-domestic uses than the alleys inside the purely residential area. The small blocks are also not able to accommodate these uses that require larger area and are fit for higher integration values. Finally, it was found that the intensified morphology as defined by the blocks’ configuration, shape and size, gives all houses direct access to the street and improves accessibility from the rest of the city.

4.2 BUILDINGS AND PLOTS
The construction of the scheme began in 1853 and lasted for 44 years, counting at the end a sum of 1243 single-family dwellings homogeneously repeated in space. The final scheme of 1897 demonstrated a collection of housing types: 28 terraced (T), 190 back-to-back row houses (BtB), 998 quarter-detached (QD) and 27 semi-detached (SD) (Jonas, 2003, p.289) in four rectangular plot types: corner, terrace, through, and end sites (Steadman, 2014, figure p.209). Three main periods of construction are identified (Figure 2).9

9 Political and economic situations such as wars and financial crisis forced the process to halt during certain years.
During the first development (1853-55), a total of 200 houses were launched in 5ha: 28 terraced (T)\textsuperscript{10} and 76 back-to-back houses (BtB), which were two-storey row houses with two or three sidewalls respectively, built on elongated parcels; and 96 quarter-detached houses (QD) on squared parcels, an invention of the architect Emile Muller called \textit{Carré Mulhousien}. These were two-storey houses grouped in four with two adjacent facades sharing sidewalls. The second stage of development towards the west (1855-70) included 660 houses (774QD and 114BtB), while the final phase (1887-97) built another 381 houses (144 QD and 27SD), occupying a total of more than 55ha\textsuperscript{11}. In this third period, the semi-detached type (SD) was introduced, a pair of mirrored houses sharing a common wall.

It is important to notice that already from the development phase of the scheme some types proved to be more successful than others (Figure 3). At the beginning, the terraced houses were the biggest types, but expensive to build and hence unpopular to sale. The back-to-back were typical working class houses. They were the cheapest and smallest of all, and continued being built until the beginning of the second cité. However, they shared three out of their four walls and performed poorly in terms of ventilation, light and sanitation. Both British typologies became quickly obsolete, letting the French \textit{Carré Mulhousien} dominate the scheme. What made this typology popular was the economy of the layout, the configuration of the built-unbuilt space and the hygiene benefits of lighting and cross ventilation. Throughout the following periods, the houses became bigger in size, and in 1891, larger semi-detached types were built for the more affluent populations.

\textbf{Figure 3 - Battleship graph for domestic built types in Cité Ouvrière from 1850 till 1900. Time (dates of construction) is mentioned on the vertical axis. The widths of bars give absolute numbers of cases built in successive years.}

\textsuperscript{10} Eight houses from the first cité were built after 1870. Hence, only 192 were completed in the first phase.

\textsuperscript{11} Including the territory of the DMC factory
5. THE DENSIFICATION PROCESS

Quickly after the completion of each phase, the standardised houses got extensively modified through piecemeal transformations made by the owners (Figure 4). Inhabitants expanded and demolished their houses, changed the roofs, facades, fences, doors, windows and gardens, opened and closed down local shops and workshops, rented out and sold entire buildings or parts of them. After WWII, many of the buildings were refurbished and in the 1960s, a high number of immigrants from Turkey, Maghreb, Italy etc arrived to Cité Ouvrière to work in the factories (Meichler et al, 1998), contributing to the properties changing many hands. The status of ownership, the flexible legislation at the level of individual buildings (Palaiologou and Kostourou, 2016) as well as the succession of multiple owners from various cultural backgrounds allowed for physical adaptations to be freely exercised, and for a variety of formal outcomes to emerge.

5.1 THE MECHANISMS OF CHANGE

A detailed on-site survey and archival research of official building permits from 1850s till 2000 shed light on the shared patterns behind the physical adaptations of the houses. We distinguish eight ‘mechanisms of physical change’ that impact the exterior articulation of the built form (Figure 5):
Figure 5 - Catalogue of formal adaptations for the three main housing types.
1. **Join together.** This mechanism occurs after one or more units are joined together to form a larger unit. It is more common for the quarter-detached type to get combined with adjacent buildings next or behind it. Sometimes, houses were joined and occupied by a single family since their construction. This mechanism has created typological mutations: quarter-detached houses turned into semi-detached, terraced or back-to-back; semi-detached to terraced; and back-to-back to terraced types.

2. **Extrude.** This mechanism refers to the addition of one or more storeys up to 11m.

3. **Extend.** This mechanism increases the floor area of the house through the addition of habitable rooms with interior connection or the elongation of existing ones owing to household needs. Again mutations of building types are created: quarter-detached have transformed into back-to-back. It is indicative that from the original 998QD, only 572 survive today.

4. **Subdivide the plot.** Upon becoming owners, the workers not only rented or sold part of the houses, but also part of the land. In many quarter-detached types, half of the original plot is sold and built by another owner.

5. **Add shed.** This mechanism considers solely detached annexations within the plots. Common annexations in the front or side yards include garages, 'gloriettes' and sheds for storage and workshops. Additions of this kind were subject to regulations with regards to building alignment, setback, access, floor area, distance from main building or neighbouring limits etc. The idea was to keep at least one third of the garden surface area unoccupied for social and hygienic purposes.

6. **Change entrance space.** Additions or modifications of the entrance porch were extremely popular and referred to horizontal growth of the house at the entrance point by adding usually non-habitable space with interior connection. Between the 1910s and 1920s, sewer and drainage systems were built, and the toilet facilities were incorporated in the entrance porches.

7. **Alter roof structure.** This mechanism summarises every possible transformation of the roof structure, such as changes of inclination, construction of dormer windows, the addition or enlargement of an attic, roof rotations and divisions.

8. **Chamfer plot corner.** This mechanism was very common to corner parcels especially after the introduction of cars as a means of transportation. The clipping followed the street alignment, and the cut-off surface was granted to the municipality.

**5.2 THE EFFECT OF CHANGE PER MECHANISM OF CHANGE**

The next part investigates the impact of each individual mechanism –all other mechanisms aside– on the built density with the use of the Spacematrix model applied at the building-plot area. In short, the Spacematrix formula can represent each built form as a 'spatial fingerprint' (Berghauser Pont and Haupt, 2004, p. 30) on a chart defined by four morphological variables of floor space index (FSI), ground space index (GSI), number of floors (L) and open space ratio (OSR). It calculates the simultaneous relationship of these variables for the specific form. Applying the formula for every building-plot compound before and after the implementation of a single mechanism demonstrates the impact of this mechanism on the density and space consumption (Figure 6).

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12 The FSI (gross floor area per plan area) expresses the built intensity of the scheme. The GSI refers to the ratio of built area to total plan area, representing the ground coverage or compactness of the scheme. The OSR variable indicates the three-dimensional spaciousness of a cubic area when the gross built area is subtracted. Finally the L expresses the average number of floors in the scheme (Berghauser Pont and Haupt, 2004, p. 25).

13 For this exercise, the eight mechanisms are applied to a building-plot area of random dimensions.
Figure 6 - Spacemate chart and calculations for showing the transformation process for every mechanism of change found in Cité Ouvrière.
This is tested on a building of 50m² (footprint) situated in plan area of 200m².
Original diagram and formula by Berghauser Pont and Haupt (2010).
Proceedings of the 11th Space Syntax Symposium

FORMAL ADAPTABILITY
A discussion of morphological changes and their impact on density in low-rise mass housing

All mechanisms of change apart from 01 [join] increase the floor space index (FSI) and ground space index (GSI) values, and decrease the open space ratio (OSR). This is obvious finding if no demolitions are happening. As the built form grows, it puts pressure on the non-built space. Furthermore, the ‘spatial fingerprints’ of all adapted forms fall within the same quadrant (red hatch of Figure 6), but differ in their trajectory of growth (red lines). For example, both mechanisms 02 [extrude] and 07 [alter roof] lead to an increase in the number of storeys (L), and therefore their trajectory follows a vertical path parallel to y-axis. This translates into a sharp rise of built intensity (FSI) without changing the figure-ground plan. In turn, the ‘fingerprints’ of mechanisms 03 [extend], 04 [subdivide], 06 [change entrance] and 08 [chamfer] retain the same height, but grow by occupying part of the open space, increasing the built intensity and compactness. This is evident when looking at Figure 4. Interestingly, Spacemate diagram fails to successfully capture mechanism 05 [add shed] for it only considers averages in the measurement\(^{15}\), and cannot distinguish between the addition of one-storey detached shed and the extension of the main two-storey house. And while in the examples of Berghauser Pont and Haupt, homogeneity was not a problem, here it seems to be.

5.3 THE EFFECT OF CHANGE PER HOUSING TYPOLOGY

The same methodology\(^ {16}\) is further used to describe the bottom-up adaptation process of the four housing typologies in Cité Ouvrière. Spacematrix model is applied separately for all the buildings falling under the same type and at two discreet chronological dates: in 1897 (original state) and in 2015 (end state). The ‘fingerprints’ (positions on the chart) are overlaid to discuss the overall performance of the scheme.

Originally, all buildings under the same type shared the same spatial fingerprint (red dots). However, since then all the different mechanisms and combinations of those applied by different owners, have led to a variety of formal outcomes, a finding which can be measured by the large number and spread of the 2015 ‘spatial fingerprints’ (Figure 7). Terraced houses demonstrate an average of 3.31 mechanisms of physical change per house, showing a preference for altering the roof [07] and adding separate spaces [05]. The average gross floor area (FSI) and ground coverage (GSI) have almost doubled, hinting at rather closed forms. However, the adapted built forms do not show a clear pattern, and the reason being the popularity of shed [05] amongst the adaptations.

Back-to-back houses have tripled in number owing to typological mutations from initially quarter-detached types. Mechanisms of adaptations are limited as the facades of houses are restricted from three sides. Hence, the morphological impact is an increase in compactness. The most popular mechanisms are: change the entrance space [06] and add sheds in the front garden [05]. Similarly, quarter detached houses have grown extensively –more horizontally than vertically owing to the plot configuration which provides open space for horizontal expansion in two directions (in front and beside). Last, even if the sample of semi-detached cases is small (similar to T), the fingerprints cluster better. The truth is that these types were already big when constructed, and no dramatic changes have been observed, apart from the addition of sheds [05].

By superimposing the ‘spatial fingerprints’ of all types (Figure 8), the overall performance of Cité Ouvrière is made visible. After the incremental densification, two clusters can be detected, indicative of two different degrees of adaptability: low (left circle) representing houses that have not received many changes or whose changes have kept the ratio between the four morphological variables unchanged; and high (right circle) which gathers the most adapted cases together. The centroids of these two clusters (average ‘spatial fingerprint’) demonstrate a clear trajectory of growth in the density of the urban form. Cité Ouvrière was and still is a

\(^{14}\) Mechanism 1 has exactly the same ‘spatial fingerprint’ with that of the original building because all the input values were doubled, so the variables remain constant.

\(^{15}\) While the FSI, GSI and OSR values increase, the L drops, which is not the case if the building height is not affected.

\(^{16}\) Due to the abovementioned shortcoming of the application concerning the heterogeneity of the sample, there are many outliers when processing the data. However, we believe the investigation remains valid as far as patterns of densification effects are concerned.
Figure 6 - Spacemate diagrams for every housing type in Cité Ouvrière. From top to bottom: terraced (T), back-to-back (BtB), quarter detached (QD) and semi-detached (SD). The red circles indicate the spatial fingerprint of the original buildings from 1897, the black dots correspond to all the contemporary cases, and the red dots on their average. Original diagram and formula by Berghauser Pont and Haupt (2010)
low-rise development (below 3 floors), which managed over time and through bottom-up adaptations to turn into a rather compact and closed built environment by consuming open space. Cité has densified its ground coverage (GSI) by almost 87.5%, increased its land intensity (FSI) while remaining low-rise. Building regulations have prohibited elevations of more than 11m, and have thus restrained changes in the number of floors (L). This forced the houses to extend horizontally, occupy more ground space, and put pressure on the garden area. As the built form became more compact and dense, the amount of non-built private space available for the inhabitants reduced. And as a consequence, regulations were soon developed to preserve at least one third of the garden area unoccupied.

Figure 8 - Top: Spacemate diagram with all the residential types. The filled dots show the original ‘spatial fingerprint’, while the ones without infill correspond to the built forms currently found on site. Bottom: Reference areas with different degrees of urbanisation defined by Berghauser Pont and Haupt (2004, p.76-77) are superimposed on the top diagram.
According to Berghauser Pont and Haupt (2004, p. 59), it is this open space ratio [OSR] and the pressure on the non-built space that determines the degree of urbanisation in an area. In other words, we can argue that the urban model of Cité Ouvrière has gradually shifted from a garden city (OSR>0.6 and L=2-10) to a more urban (GSI>0.2, OSR>0.4 and L>3) and in cases, to a highly urban area (OSR<0.5). Implications of this urbanisation process were also observed in the increase and diversification of the volume geometry, which led a large number of identical houses to end up looking fairly different from each other (Figure 4). This was the result of an indefinite combination of different types of changes per house. So, despite the apparent standardisation of built forms and subsequently building regulations and planning policies at the neighbourhood level, a variety of formal and typological outcomes have emerged as a result of the spatial affordance of the original design at the level of the individual block-plot compound.

6. CONCLUSION

This paper looked at the physical adaptations of the street network, buildings and plots in Cité Ouvrière, a nineteenth-century mass factory housing from 1853 till now. It adopted a morphospatial methodological approach, which studied adaptability as an evolutionary process in time and at different scales. The aim was twofold: to describe the evolution of the urban form (streets, buildings and plots), and understand adaptability as a matter of density.

One main conclusion is that depending on whether mass housing is defined as the sum of its parts –buildings and plots– or by its position in the city –street network–, the definition of adaptability changes. On the one hand, for the street network, adaptability is defined as the ability of the system to withstand and endure changes. Over time, its configurational performance has been enhanced by adaptations that took place in its immediate surroundings. In the context of Cité Ouvrière, adaptability at the street level was dependent on three factors: first, the internal morphology of local layout; second, the way the city expanded to encircle the area and third, the self-refining relation of the local grid to the city network. On the other hand, for the buildings and plots adaptability is defined as the capacity of the built form to accommodate effectively changes over time. In this low-rise mass housing the transformative aggregate effect of individual physical adaptations contributed to the transformations of a uniform garden city into a formally diverse and dense old city quarter.

Effectively, it can be argued that for low-income housing schemes physical adaptations can have positive effect on the performance of the built form, when certain morphological characteristics have been integrated in the original design: first, location of the scheme which allows adequate accessibility to plots; secondly, low built intensity which does not maximises plot coverage and third, provision of small plots with high ratio of non-built space in double adjacency. Evidence indicates that the surplus open space is a key enabler for individual building-plot compounds to accommodate future growth, and a precondition for densification.

Finally further research needs to follow to fully understand the relation of adaptability at the three levels: the street network, the buildings and the plots form the single perspective of form. Recently, Törmä et al (2017) argued that although morphological properties in the street network such as accessibility afford socio-economic changeability, there is no straightforward link between network configuration and physical changeability. We speculate that future explorations could link the characteristics of the street network with adaptations of buildings and plots by focusing on the properties of the interface.

ACKNOWLEDGEMENTS

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REGIONAL MORPHOLOGY

The Emergence of Spatial Scales in Urban Regions

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ABSTRACT

In space syntax, cities are thought of as emerging from a dual process of a global network shaped by micro-economic factors and a local network of residential space shaped by culture. This theory is based on an understanding of cities as independent entities. Cities, however, cannot be understood in isolation and often stay in complex relation to their surrounding and other cities. Departing from the notion of spatial configuration, this paper challenges the paradigm of what is considered as ‘the city’. It goes beyond the fuzzy boundaries of cities and sets the economic functioning of urban form into regional context. It will be argued that space syntax concepts of ‘global’ and ‘local’ scales are in regional configurations not applicable anymore and a better understanding of spatial scales in the context of space syntax as well as their emergence is needed. Revisiting Christaller’s (1933) central place theory of the economic distribution of urban space, this study makes an attempt of theorising the relationship between geographic economy and spatial configuration of regions. This is done by investigating a large set of different centrality structures in two polycentric urban regions, taking a method proposed by Serra and Pinho (2013) as a point of departure this study employs an exploratory factor analysis to investigate hidden centralities. The term latent centrality structure (LCS) is introduced to describe the phenomenon of emergent spatial scales that can be seen as influencing centrality patterns within polycentric urban regions. The findings suggest a need for a revision of the theorisation of the concept of ‘global’ and ‘local’ scales in light of space syntax analysis towards multi layered LCS’. This study shows that space syntax can be applied in regional contexts and gives further guidance on a methodology to explore regions through space. However, additional research is needed to confirm whether the found LCS’ have implication to empirical flow data as well as if they have relevance in a socio-economic context and hence be of use to inform regional policymaking.

KEYWORDS
Morphology, Region, Space Syntax, Scale, Exploratory Factor Analysis

1. INTRODUCTION

Cities and regions are increasingly converging. This is not only materialising in the real world but can also be observed in newly arising theoretical debates. It has been argued that globalisation has led to a new type of urban morphology, the polycentric urban region (PUR) (Hall and Pain, 2006). Knowledge of configurational properties of regions in general and PUR’s in particular is still in its developmental stages. However, with growing computational power and access to large data sets configurational studies of regions are increasingly becoming feasible. This study tries to shed light on regional spatial configurations. On practical level, analytical ventures in regional spheres pose a series of challenges and questions, starting with the generation of
computable models, over how to define model boundaries, or the level of detail and resolution, towards which radii to choose in the analysis. These questions, however, are not technical but theoretical in nature and, it will be argued, relate all to the question of what ‘scale’ is in space syntax. The aim of this study is hence to understand spatial scales in regions and how they emerge.

The paper is structured into three parts; the first part forms a theoretical contextualisation. We will review preceding space syntax studies dealing with metropolitan and regional cases. Through a comparison of the methodology of these studies and a revision of the meaning of ‘global’ and ‘local’ radii in the analysis and space syntax literature, it will be argued that there is a need for a conceptualisation of scale in space syntax. Such a concept of scale is particularly needed when investigating regions. The initial attempt to conceptualise scale in space syntax builds on Christaller’s (1933) central place theory (CPT) of the economic distribution of urban space.

The second part will introduce the chosen methodology to investigate the emergence of previously outlined scales in regional spatial configurations. Two selected case studies are presented, as well as a randomly generated planar regional model. We will elaborate on the process behind the generation of this randomly generated planar model and the reasoning behind a comparison of real world cases with such model. Finally, the selection of different centrality measures as well as the method of exploratory factor analysis will be justified.

The third and final part presents the analytical results and sets the findings in the theoretical context of the concept of scale in space syntax.

2. REGIONAL ANALYSIS AND THE MEANING OF SCALE IN SPACE SYNTAX

Only very few space syntax studies have set the region at the focus of analysis. Turners (2009) study into the linkage of the local to regional continuum forms here a pioneering position. Not only due to his methodological proposition to make use of a road-centre line data for his analysis, but by focusing on a collection of cities in the regional context. The application of network analysis in the field of regional studies opens up the possibility of new understandings of spatial relations. Space syntax, applied to a regional scale however unveils some challenges as it is theorised in a fundamentally local context, the human body in space, which has not been explored so far in a regional context.
Table 1: List of space syntax studies dealing with the regional and metropolitan scale, from 2007 – 2015.

<table>
<thead>
<tr>
<th>Year</th>
<th>Author(s)</th>
<th>Title</th>
<th>Location</th>
<th>Scale</th>
<th>Methodology</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>Krippendorf</td>
<td>Space Syntax in Regional Planning</td>
<td>Germany</td>
<td>Regional</td>
<td>Network analysis</td>
<td>Identifies key nodes and paths</td>
</tr>
<tr>
<td>2008</td>
<td>Buckles et al.</td>
<td>Urban Morphology in Metropolitan Areas</td>
<td>USA</td>
<td>Metropolitan</td>
<td>Quantitative analysis</td>
<td>Identifies urban clusters</td>
</tr>
<tr>
<td>2009</td>
<td>Tzonis &amp; Lefaivre</td>
<td>Spatial Scales in Metropolitan Planning</td>
<td>Europe</td>
<td>Metropolitan</td>
<td>Qualitative analysis</td>
<td>Identifies hierarchical patterns</td>
</tr>
<tr>
<td>2010</td>
<td>Batty et al.</td>
<td>Space Syntax in Urban Regions</td>
<td>Canada</td>
<td>Regional</td>
<td>Spatial database analysis</td>
<td>Identifies boundary effects</td>
</tr>
<tr>
<td>2011</td>
<td>Johnson &amp; Ondrovic</td>
<td>Regional Space Syntax</td>
<td>Australia</td>
<td>Regional</td>
<td>Mixed methods</td>
<td>Identifies regional integration modules</td>
</tr>
<tr>
<td>2012</td>
<td>Krumweide</td>
<td>Metropolitan Space Syntax</td>
<td>China</td>
<td>Metropolitan</td>
<td>Network analysis</td>
<td>Identifies core regions</td>
</tr>
<tr>
<td>2013</td>
<td>Lee &amp; Kim</td>
<td>Regional Space Syntax in East Asia</td>
<td>Japan</td>
<td>Regional</td>
<td>Quantitative analysis</td>
<td>Identifies key corridors</td>
</tr>
<tr>
<td>2014</td>
<td>Li et al.</td>
<td>Space Syntax in Metropolitan China</td>
<td>China</td>
<td>Metropolitan</td>
<td>Spatial database analysis</td>
<td>Identifies urban corridors</td>
</tr>
<tr>
<td>2015</td>
<td>Zhang et al.</td>
<td>Space Syntax in Chinese Cities</td>
<td>China</td>
<td>Regional</td>
<td>Mixed methods</td>
<td>Identifies urban networks</td>
</tr>
</tbody>
</table>

1 Space syntax studies in regional or metropolitan context
With a view on recent space syntax studies dealing with the ‘regional’ continuum some commonalities and differences do reveal (Table I). The most apparent observation is a non-defined usage of the term ‘region’. This is rooted in difficulties with the very definition of the entity itself and most obvious in the difference of model sizes, which range from 20 to 950km. Particularly the term metropolitan area seems to be often used synonymously for region, which makes the comparative application of findings problematic. Additionally to differences in model sizes, does come a variety of different model types. These types vary from manually drawn axial lines by researchers, over models based on governmental data to models based on voluntarily geographic information. Also the level of detail and resolution within each model differs from an inclusion of all open spaces to analysis based only on upper tier highway systems. Adding to this variation in each approach, a not consistent use of space syntax measures and their respective scales of analysis are present. All of this is on one hand due to the constant development of analytical procedures and technologies in the field and on the other due to the developmental stage of regional studies in the field of space syntax. This situation poses difficulties in the comparability of findings.

When this study refers to the term region and PUR, it builds on concepts of geography. In geography the term region is broadly applied to three fundamental territories, trans-, supra- and sub-national (Trippl, Maier and Tödtling, 2012, p. 13). While supra-national territories are regions that can be consolidated of several nations across the globe (Latin-America, south-east Asia) and trans-national territories, regions that are across two or more adjacent states (EUREGIO, ARGE), this studies interest is of the third kind and can be described as sub-national territory (ibid., p.14). Sub-national regions are within one independent nation and share, contrary to trans- and supra-national territories, the same political and socio-economic systems. As stated earlier the object of this research is a particular type of region within the category of sub-national territories, namely the PUR. The concept of polycentrism in general is often used to describe a hierarchical organisation and refers to ‘the spatial clustering of almost any human activity’ (Kloosterman and Musterd, 2001, p. 623). Polycentric entities are hence characterised by a clustering of human activity leading to a complex spatial organisations. Polycentric urban regions are such polycentric entities. They consists of a number of historically distinct, political and administratively independent cities in close proximity to each other (Kloosterman and Lambregts, 2001, p. 718). Important is the lack of a dominating central city and a rather even distribution of a smaller number of similar sized cities with equal economic importance and a greater number of smaller cities (ibid., p.719). This is because regions that feature a dominating central city are usually characterised by a stronger hierarchical relationship between urban spaces towards the centre. There are other terms used to describe such polycentric urban regions, such as ‘city-region’ (Scott, 2002), ‘city networks’ (Camagni and Salone, 1993), or ‘network cities’ (Batten, 1995). The interest in using PURs as cases studies is because of their inherent complexity of their spatial organisation.

Contrary to the explorations in space syntax studies in metropolitan and regional form are the majority of preceding studies applying network analytical approaches to the scale of the ‘city’. The city in these studies is mostly defined by natural or administrative boundaries. Each model consists of one independent city. These investigations have lead to a series of cross country comparisons of cities and their morphological structures and give valuable insights into their socio-economic functioning (Figueiredo and Amorim, 2007; Peponis et al., 2007; Hanna, 2009). Most recently Hillier et al. (2012) have pointed out, in their study of 50 different cities that there seemingly is a globally occurring dual relation between a global and local structures of cities. This dual relation has been theorised by Hillier as the generic city (Hillier, 2014). The 50 different cities, Hillier et al. compared in their 2012 study varying in size significantly. So are the three smallest networks in their list of cities, Mytiline, Nicosia and Venice approximately 1km, 1,5km and 5km wide, whereas the largest networks include Istanbul, Beijing and London with approximately 26km, 34km and 64km. The largest system is hence 64 times larger than the smallest system. For Hillier et al. (2012, p. 164) such a comparison is nevertheless appropriate, because they developed a method to normalise betweenness centrality deriving with a range of comparable values, which they argue ‘permit direct comparison of radii within and across cases’ from ‘local to global’. They argue that their analytical approach allows comparison across
different sizes as the systems under investigation feature the same unit, namely streets and hence ‘share the same scale and mean the same thing’ (ibid., p.167). What is referred to here, as ‘scale’ could be better described as ‘resolution’ and does not sufficiently account on scale as a whole.

While they do not specify what they refer to as ‘local’, they proceed in their analysis to investigate the ‘global pattern’ of each city comparing radius $n$, or in other words all segments with all for each case. Such a comparison is here seen as rather problematic due to the following reasons: a) the boundary selection has a strong impact on the observed structure. This impact has been termed ‘edge effect’. The model of the city of Tokyo and Beijing for example are a cut outs of larger continuous metropolitan agglomerations and areas at the border of the model are hence not representing a fragmented network of the real world situation. A study by Gil (2015, p. 2), demonstrated that ‘centrality measures are affected differently by the ”edge effect” and that the same centrality measure is affected differently depending on the type of distance used’. This effect is stronger the larger the applied radius is and consequently affects radius $n$ the most; b) radius $n$ is not a distance free measure. Rather it is the radius distance necessary to capture the two segments in the graph that are the furthest away from each other. In other words radius $n$ has a precise distance, it is the longest shortest path (or the network geodesic) of the system. We can assume that for example for the model of Mytiline radius $n$ is slightly larger than the geographic distance of the model boundary $\geq 1\text{km}$, whereas for the model of London radius $n$ similarly must be something $\geq 64\text{km}$. When comparing these two betweenness centrality structures, the comparison is hence based on one structure that exhibits movement on a very small radius (some might refer to as ‘local’) and another structure of a very large radius (some might refer to as ‘global’).

Both difficulties are rooted in the lack of theorising scale in space syntax and the fact that the radius of what is considered ‘local’ and ‘global’ changes dramatically through out the body of space syntax literature depending on the object under investigation. The general use of the term is initially derived from cellular spaces and graph theory terminology, but departed at later stages to the context of society above and beyond network relationships. First referred to by Hillier et al. (1976, p. 153), ‘local’ and ‘global’ was used in a descriptive context of cellular agglomeration patterns derived from a simple rule sets. Here, ‘local’ refers to an individual cell and its rule, while ‘global’ describes the agglomerated object as a whole, that is all individual cell’s together, and their subsequent derived global structure. For Hillier et al. (1976) it is not of particular importance at which scale ‘global structure’ emerges or if there are other structures in-between, rather their focus is on the theoretical positioning that it emerges at all and its subsequent implication for the observed entity. While it is clear in the context of cellular spaces what is meant when the term ‘local’ and ‘global’ is used, it becomes vague when the authors convey their concept to real world examples, where it will be argued scale becomes an intrinsic aspect of any analytical endeavour. Cellular agglomerations are theoretical constructs and ultimately non-spatial and hence do not feature spatial scales, what differentiates them is their topological relationship. When network principles are applied to real world spaces, scale does become an important factor. This is because, when leaving the theoretical sphere of non-spatiality, geometrical characteristics, such as metric distance become an important factor of differentiation (Salheen and Forsyth, 2001). If ‘global’ relates to the agglomeration of all human journeys in space, and as a product generates a spatial configuration subsequently shaping movement, then all journeys can only refer to those taking place within the model and hence exclude any inter city relationships. A large body of work in the field of mathematical methods of spatial analysis dealing with the spatial organisation of society on inter city and regional relationships was already established at the time when Hillier et al. (1976) first sketched their notion of space syntax, but the authors decided to not engage with these strands due to fundamental differences in their conception of distance and space. The outcome of this decision becomes particularly apparent when, Hillier et al. (ibid.) transfer their theoretical models on real world examples. When the scale less model becomes spatialised—and hence starts to incorporate scales—in forms of buildings, neighbourhoods and settlements of ranging size, the term ‘local’ and ‘global’ starts to refer to entities of entirely different size. The authors bridge these differences with the terminology of ‘small’ or ‘large’ scales, or synonymously levels
(ibid., p.183) while simultaneously describing ‘local’ and ‘global’ characteristics of the respective system. What is here considered as ‘global’, however, needs to be seen in the context of each respective spatial scale.

The reasoning behind this can be found in ‘The Social Logic of Space’, where Hiller and Hanson state that they deliberately excluded notions of distance and location in their theory, arguing that space syntax is ultimately distance free and that the notion of location can be replaced by the notion of morphology, enabling the incorporation of an entire set of simultaneous relationships (1984, p. xii). They further argue, it is the analysis of these simultaneous relationships and ‘the global properties of such complexes of relations’ that allow revealing hidden structures, which prior approaches building on distance notions have missed to provide (ibid., p.xii). Such global properties reveal indeed hidden structures, but as argued earlier the comparability of these properties across systems seems unclear and becomes difficult in regional applications. Hiller and Hanson’s decision to exclude the notions of distance and location from their theory prevented a possible convergence of developments of mathematical methods of spatial analysis in quantitative geography. Particularly the work of Peter Haggett (1965) and his colleague Richard Chorley (1967, 1969), Richard Morrill (1970) as well as Abler et al. (1971) focused on finding patterns of spatial relations and their geometric network properties, as well as stressing the importance of distance in human spatial organisation. It comes hence rather surprising that this strand of though was not incorporated or converged, which might be an explanation of the vague concept of scale in space syntax literature. However, Hillier and Hanson have expressed their appreciation for the theories of von Thünen (1826), Christaller (1933) and Lösch (1940), but did not incorporate their notions into the broader theory. All of the named authors played an important role in the development of the field of quantitative geography and deal specifically with the notions of distance and location. A view on a quote by Peter Haggett from 1965 exemplifies the very proximity of his thinking to the one of Hillier and Hanson.

‘One of the difficulties we face in trying to analyse integrated regional systems is that there is no obvious or single point of entry. Indeed the more integrated the system, the harder it is to crack. Thus in the case of nodal regions, it is just as logical to begin with the study of settlement as with the study of routes. As Isard comments: “the maze of interdependencies in reality is indeed formidable, its tale unending, its circularity unquestionable. Yet, its dissection is imperative. ... At some point we must cut into its circumference.” We chose to make that cut with movement.’ (Haggett, 1965, p. 31)

Both authors see the entry point of analytical ventures in understanding human spatial organisation in the study of streets with the focus on movement at its core, opening up points of contact. With the developments in the field of space syntax during the last decade, particularly the development of angular segment analysis and the introduction of metric distance radii (Turner, 2003; Hillier and Iida, 2005) the possibility of a point of connection has been established. While the majority of space syntax studies puts the focus of their research on the city, quantitative geography departed early on towards an understand of regions as integrated systems of different settlements. This is particularly the case for the geographic strand of economic theories, which started with a one-city theory (von Thünen, 1826) and moved to a system of different hierarchically ordered cities (Christaller, 1933) into what is now coined as a more complex network-based relationship of cities and their hinterland (Sassen, 1991; Taylor, 2004).
We believe that particularly Walter Christaller’s Central Place Theory (CPT) (1933) of hierarchical order can bring valuable insights into the emergence of scales. This is because, albeit the fact that several investigations and practical applications on real world examples have shown, that regional distribution of urban areas must follow a more complex relationship, up to now there has not been a better self-consistent theory of economically driven human spatial organisation. Christaller analysed and categorised different sized urban areas and their relationship based on retail services to their surrounding rural area (ibid.). The notion is based on the idea that cities are points of economic exchange. This economic exchange follows a hierarchical order in such a way that specific economic trades occupy particular areas of potential distribution and compete with trades of the same kind spatially. This leads subsequently to an economic even spatial distribution with efficient accessibility for each of the trades (Figure 1:1a) and to a hierarchical spatial network. Settlements that are central located offer more goods and services and have larger populations. Relative locational centrality is the fundamental determent for his notion. For Christaller, albeit investigating a fundamental spatial phenomena—the hierarchical spatial distribution and size of cities—his conceptualisation of the city is one of abstract nodes within a networked economy. Nevertheless, Christaller’s central place system does not come without any spatiality. For Christaller spatiality is thought of as distance and market area (Figure 1:1b). Ultimately, regions are for him networks of nodes with edges of a given radius. His central place system is hence divided in seven hierarchical level of urban from (Table II), ranging from a small town Marktort with a population of a 1,000 up to large scale cities Landstadt with populations larger than 500,000. Each hierarchy features a potential market population as well as a given market radius.

Figure 1 shows how his theory manifests if mapped to the case of southern Germany. Here L centralities form the upper network of interconnected centres. In the order of P, G, B and K centres are then cluster around the respective next upper level. Particular for his model is that relationships are inherently one directional, this means that each lower class depends on the level above. Since each level is characterised by a, for the hierarchy relevant, cluster of particular economies, horizontal interdependencies are considered as redundant and hence none existent. This implies that interregional relationships do only exist on the level of large metropolitan cities. Many authors have extended the theory, Berry (1961), Bourne et al (1978) and Haggett (1969) among others (See Coffey (1998) for an extensive review).
What differentiates Christaller’s CPT theory from a space syntax approach is that distance albeit metric in nature is theorised as direct connecting line between nodes, rather than considering distance through the human shaped configuration. Christaller’s theory is a strong simplification that takes place in an ideal plane space. His aim was to understand the distribution of cities, rather than the immediate morphology that such a process produces. Space syntax, on the other hand provides methods and tools to explore the morphology of spatial configurations and if Christaller’s theory has validity then there is more human activity on scales of market spaces than on other scales. This would subsequently lead not only to the pattern of city distribution that Christaller described, but to a particular polycentric spatial configuration reflecting these scales.

The notion of scale has long been a mayor concern for the geography discipline in general. Over the last decades several authors have stressed the importance of scale (Harvey, 1969; Watson, 1978; Meentemeyer, 1989) and this is particularly the case for physical geography and remote sensing in GIS (Quattrochi and Goodchild, 1997). When dealing with geographic data, it is inevitable to specify the respective scale of investigation. Lam and Quattrochi (1992) summarise the core notions on spatial scale and related difficulties when dealing with spatial processes in a triad of cartographic, geographic and operational scale. Here, cartographic scale refers to the ratio between the mapped representation and the real world. While, geographic scale relates to the spatial extent or the scope of the analysis, operational scale gives an account of the level at which the respective process operates. In addition to this scale can also be interpreted as the level of detail, or resolution (ibid., p.89). For the authors one of the core reasons for the importance of dealing with precise definitions when talking of scale is that spatial patterns are usually related to a precise scale and different processes might lead to similar spatial pattern (ibid., p.89). A situation that makes it necessary to define the spatial extent and the spatial
resolution of any data and its analysis in order to investigate at which scale processes operate. This is particularly the case since the advancement of GIS allows cross comparisons of different scales, albeit their potential meaningless outcome.

Apart from these data related aspect of scale in physical geography a large body of work in human geography has been dealing with scale on a theoretic level. Here, the focus is in particular on understanding how ‘the production of scale is implicated in the production of space’ (Marston, 2000).  

Erik Swyngedouw (2004, p. 129) argues, that the social and physical transformation of the world is taking place in an ‘interlocked and nested geographic scale’. For Swyngedouw social life is process-based, and constantly iterates, transforms and reconfigures itself. This process stays in a reciprocal relation to nature and produces in its appropriation and transformation ‘historically specific and physical natures that are infused by a myriad of social power relationships’ (ibid., p.130). These ‘Socio-spatial relations operate over a certain distance and produce scalar configurations’ (ibid., p.131). Swyngedouw brings with his notion of environmental transformations as integral parts of social and material production of scale, the opportunity to perceive such scalar relationships through space. What Swyngedouw describes are scales that manifest themselves in space. Since these scales are in their generation dynamic and process-based, Swyngedouw argues ‘Starting analysis from a given geographic scale seems […] to be deeply antagonistic’ (ibid., p.132). For him differently to Christaller’s CPT, are scales not primarily shaped by economic activity, but by human activity and the very nature of social life. Swyngedouw further emphasizes that scales incorporate complex power structures that govern social relations (ibid., p.131). This is because scales generate geometries of power that produce advantaged and disadvantages in their very existence. In space syntax terminology one can speak of integrated and segregated locations, or as Stephen Read (2013, p. 10) has put it in his typology of urban levels of ‘being in or out of the network’.

Based on these two notions, one can conceptualised scale, in the context of space syntax. Scale, is hence the structure shaped and constantly reshaped by socio-spatial and economic processes, operating over a certain distance and time. While the process shaping the scale structure can stay in a quick and constant transformation, the spatial scale is believed to be changing in a rather inert way. Spatial scales are nevertheless in Swyngedouw’s words ‘never fixed, but perpetually redefined, contested and restructured in terms of their extent, content, relative importance and interrelations’ (2004, p. 133). When analysing spatial networks on different centrality radii the patterns that one can observe are constantly influenced by this underlying scale structure that is manifested in the very configuration of the network. It is believed that in order to understand the fundamental morphology of a region, one needs to unveil this hidden or latent scale structure, or in other words this multi levelled interrelated system of spatial scales that cause certain centrality patterns to emerge. Instead of starting from the dichotomy of the ‘local’ and ‘global’ radii in the analysis, the spatial configuration needs to be understood through an extensive collection of different metric radii.

3. DATASETS AND METHODOLOGY

Serra and Pinho (2013) have dealt in their seminal study on the structure of the metropolitan city of Oporto with a similar problem. They investigated closeness centrality structures on 15 different radii and proposed a principle component analysis (PCA) to arrive with a reduced dimensionality of these radii (ibid., p.186). Their findings consisting out of three components, theorised as: neighbourhood, city and regional scale, highlighted to be seen as ‘natural centrality scales’ and ‘intrinsic hierarchical organisation of metropolitan centres’ (ibid., p.190). The reason behind using a PCA analysis in their study was to arrive with ‘variables that are contained, albeit not explicitly, in the original one’ (ibid., p.189). As outlined in the previous section the aim of this study is to unveil the latent structure causing centrality patterns to emerge. For this purpose an exploratory factor analysis (EFA) will be applied to a series of radii. PCA and EFA are often confused as similar, or in the case of PCA as a simpler form of EFA, this is assumption is not correct, because PCA is using a different mathematical model than

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1 See Marston et al. (2005)—albeit their contested criticism on the existence of scales in human geography—for a comprehensive review on scale related literature of the past 20 years.
EFA and is different in several aspects (Widaman, 2007; Fabrigar and Wegener, 2011). This is because PCA ‘was not originally designed to account for the structure of correlations among measured variables, but rather to reduce scores on a battery of measured variables to a smaller set of scores (i.e., principle components)’ (ibid., p.31). PCA derived components’ main purpose is to explain as much variance as possible from the original measured variables, rather than to explain the correlations among them (ibid., p.31). In this sense PCA is an efficient method to represent information in measured variables. EFA on the other hand produces common factors. These factors are unobservable latent constructs that are conjecturally cause the measured variables (Costello and Osborne, 2005; Fabrigar and Wegener, 2011, p. 31). Different to a PCA, which constructs components directly from the measured variables does the EFA common factor model divide the variance in measured variables into common variance and unique variance (Figure 2).

The reasons why EFA has been chosen over the proposed PCA are, because a) the general aim of this research is to identify latent constructs (spatial scales) that are presumed to cause the measured variables (centrality pattern), to inform a broader theory building and is has been argued that EFA is the appropriate method for this (ibid., p.32), b) EFA is designed for cases ‘in which the researcher has no clear expectations or relatively incomplete expectations about the underlying structure of correlations’ (ibid., p.4) as it is the case for this research, and c) different to PCA does EFA generate parameter estimates that allow a generalisation beyond the measured variable collection on which they are based (Widaman, 2007). This means PCA resulting components and component loadings change with every adding or removal of additional variables. In the case of EFA, however, adding more measured variables (or radii) does not alter the parameter estimates such as respective factor loadings for original measured variables, unless they rely on a new common factor that was not present in the original measured variable collection (Fabrigar and Wegener, 2011, p. 33). If one includes enough radii in the analysis to make sure the differences between each radius are small enough one can presume that all existing factors are captured. These advantages make EFA more robust in the context of radii selection and investigations of scale structures. This study will hence employ an EFA to extract latent centrality structures, conceptualised as spatial scales that are presumed to cause centrality patterns of different radii.

Figure 2 - Illustration of the Common Factor Model for an example involving three common factors and nine measured variables.

The reasons why EFA has been chosen over the proposed PCA are, because a) the general aim of this research is to identify latent constructs (spatial scales) that are presumed to cause the measured variables (centrality pattern), to inform a broader theory building and is has been argued that EFA is the appropriate method for this (ibid., p.32), b) EFA is designed for cases ‘in which the researcher has no clear expectations or relatively incomplete expectations about the underlying structure of correlations’ (ibid., p.4) as it is the case for this research, and c) different to PCA does EFA generate parameter estimates that allow a generalisation beyond the measured variable collection on which they are based (Widaman, 2007). This means PCA resulting components and component loadings change with every adding or removal of additional variables. In the case of EFA, however, adding more measured variables (or radii) does not alter the parameter estimates such as respective factor loadings for original measured variables, unless they rely on a new common factor that was not present in the original measured variable collection (Fabrigar and Wegener, 2011, p. 33). If one includes enough radii in the analysis to make sure the differences between each radius are small enough one can presume that all existing factors are captured. These advantages make EFA more robust in the context of radii selection and investigations of scale structures. This study will hence employ an EFA to extract latent centrality structures, conceptualised as spatial scales that are presumed to cause centrality patterns of different radii.
The models used in this study are based on two European polycentric urban regions, the German region of the Ruhr Valley (from here onwards GE) and the British region of Nottinghamshire, Derbyshire and Yorkshire (from here onwards UK). Both regions are strongly influenced by processes of industrialisation and comparable in their historic development. The real world street network models for both regions are based on OpenStreetMap road-centre line data. The models boundary are of circular shape with a diameter of 230km centred on the approximated geographic mid point of each region, this is to avoid edge effects in the regions under investigation. The GE model contains 1,203,173 segments with a total segment length of 122,707.61km, whereas the UK model contains 1,019,915 segments with a total segment length of 107,542.92km. This leads to an area coverage of 41,547km2 including a population of more than 14,000,000 inhabitants in both cases. The networks are manually checked on consistent network coverage and simplified using a semi-automated ArcGIS simplification workflow (Krenz, Forthcoming 2017). The model coverage is defined by all components of the public rights of way network. The simplification is based on an average width of each street level and defines the models resolution. The models form the first of their kind on the scale of sub-national territory with a resolution and comprehensive network information from the smallest urban path to large motorways.

In addition to this, the study makes use of a randomly generated street network on a regional size as a mean of testing if spatial scales are an intrinsic part of spatial networks. Automated street network generation does not form a trivial task. While there are several approaches dealing with street network generation in general, approaches that produce entirely random networks are scarce. This study will build on the algorithmic approach of an Erdös-Rényi random planar graph (ERPG), proposed by Masucci et al. (2009). Different to the ERPG are most of the available procedures to generate street networks parametric in nature. Such parametric approaches use either a set of generative rules in order to arrive with street networks (Parish and Müller, 2003; Marshall and Sutton, 2013), others employ pattern based approaches to generate networks (Sun et al., 2002), or a combinatorial approach of both (Chen et al., 2008).

Parish and Müller (2001) introduced CityEngine, a procedural method that allows consideration of global goals and local constraints. Sun et al. (2002, p. 42) for example identified a series of existing frequent pattern in real world networks and created a matching pattern template for each. Through the application of different pattern templates they are able to generate new street that are combinatorial. Chen et al. (2008) on the other hand combine Parish and Müller’s (2001) procedural method with a tensor field to generate pattern. Most recently Marshall and Sutton (2013) presented the simulation tool NetStoat to model the growth of street network. Their tool explored the potential of generative street layouts. This list should not be seen as a complete account on generative network tools, but as a rough guide towards the general approach taken in this field.

All of these parametric approaches emulate networks based on cities. It stays in question if these network structures are comparable to structures of regions. Moreover, none of the parametric approaches can be considered as random in nature, but this is a necessity for the model we want to employ. If the model does not feature a strong degree of randomness then the results of the analysis will exhibit centrality pattern of emulated human shaped configurational environments. Contrary, the aim of the planned test is to gain insights into fundamental network characteristics of regional sized models that are not shaped by human interaction and are instead random by nature. This is why an ERPG is selected for the generation of the model. An Erdös-Rényi random graph is a graph with a given number of vertices \( n \), and the probability of an edge \( p \) between two randomly selected vertices with equal likeliness. Erdös-Rényi random graphs’s are \( O(n^2) \) problems (Gerke et al., 2008), and hence take long time to process if \( n \) is significantly large (\( n \geq 1,000,000 \)). An ERPG is a variation of the Erdös-Rényi random graph. Differently to the original Erdös-Rényi random graph, introduces the ERPG proposed by Masucci et al. (2009, p. 261) a selection process that tests each edge on planarity, that means, on a possible intersection with already existing edges in the graph. An edge will only be added to the graph during the process if no intersection with an already added edge has been found. Moreover, we introduce an additional restriction to the Masucci et al. ERPG, that is a segment length frequency selection,
which is derived from the two real world regional models. This selection process will increase the probability of segments of certain lengths in order to arrive with a higher comparability.

The final ERPG, will hence feature equal number of nodes, equal number of edges, a comparable frequency of segment length, and the same model boundary diameter as the two real world regional models. The difference between the models is in their spatial distribution of each segment, or in other words, the ERPG is a graph that does not inherent the effect of human action in its emergence. This will allow a comparison with the morphology shaped by human interaction and a morphology that is random in nature in order to identify centrality pattern that are inherent to any spatial network.

<table>
<thead>
<tr>
<th>Bins</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Segments</td>
<td>1000</td>
<td>4000</td>
<td>25000</td>
<td>70000</td>
<td>900000</td>
</tr>
<tr>
<td>Maximum distance</td>
<td>5200</td>
<td>1300</td>
<td>800</td>
<td>400</td>
<td>200</td>
</tr>
<tr>
<td>Minimum distance</td>
<td>1300</td>
<td>800</td>
<td>400</td>
<td>200</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Table 3 - Segment frequency binning based on top 95 percentile.

To arrive with the outlined ERPG, this study developed an algorithm using R (2016) a programming language for statistical computing. Building on the strategy proposed by Masucci et al. (2009, p. 261), the ERPG process builds on a Poisson point process of n points in a Euclidean space of circular shape and a diameter of 230km. Differently to Masucci et al. (ibid., p. 261), to overcome the long time needed to compute a model of more than 1 million edges, an initial k nearest neighbour algorithm is employed to find a set of point pairs in a given maximum distance for every point of the Poisson distribution dataset. The given maximum distance between two edge pairs is based on the longest segment found in the two real world models. The result is a matrix of edge pairs with a distance from 0.1 to 5000 metres. Based on this nearest neighbour dataset a random selection of point pairs is chosen and subsequent a line segment added to the graph. The point pair selection is limited by an average segment length frequency found in the existing two regional models, derived through the average of five frequency bins of both real world models (Table II). Any following line segment is then evaluated against possible line intersections and dismissed if true, in order to arrive with a planar graph. The algorithm proceeds until a previously defined maximum number of segments are generated. Figure 1 shows a detailed section of each of the models on a scale of 1:10,000. The different network morphologies of the automated ERPG are visible (1c).

Figure 3 - Regional street networks, detailed sections (1:10,000) of the three different models, GE (1a), UK (1b) and ERPG (1c).
These three models are analysed on the centrality measures of angular segment analysis (ASA) segment length weighted (SLW) betweenness centrality (Turner, 2002, 2005). ASA SLW betweenness centrality is similar to mathematical betweenness (Freeman, 1977), which calculates how often a segment has been chosen as part of a shortest path between every pair of segments on a specific cut off radius. Hillier (2009) has theorised this as a measure of accessibility or through-movement and linked it to the economic function of urban form. It should be noted that ASA closeness centrality might show additional interesting insights into regional morphologies, as the seminal study by Serra and Pinho (2013) has already demonstrated, however, two reasons lead to the focus on betweenness centrality only, a) betweenness centrality has been associated with economic functioning of urban space (Hillier, 2009) and Christaller’s CPT is focused on the spatial organisation of economic activities, it makes hence sense to investigate on those centrality patterns that can be related to the theoretical positioning of spatial organisation of economic activities, moreover, b) initial tests have shown that closeness centralities generates unexpected outlier where the network structure forms linear cluster, see appendix I. Although this issue can be resolved with the method provided in appendix I (exhibiting how to detect such outlier segments) further tests are need on the effect of such outliers on centrality patterns across different radii.

Because there is no established method to select radii so far, this research bases its analysis on 49 different radii that have a smaller metric difference on small radii and grow in difference with larger radii, accounting for the growing computational time and fewer differences on larger radii. Moreover, the smallest radius is selected based on the mean segment length found in the two regions (GE: 101.99m, UK: 105.44m), while the distance differences between each radius is smaller than the longest segment in each system (GE: 5777.72m, UK: 4732.78m). The reason behind this is to analyse a large collection of radii with only small differences between them to be able to capture any scale of they exist. If each of the scales correlates strongly with the next one, the assumption can be made that there is no hidden scale between the two, which is not covered by the analysis. The selected radii are: 100, 150, 200, 300, 500, 800, 1300, 1800, 2500, 3200, 4100, 5000, 6100, 7200, 8500, 9800, 11300, 12800, 14500, 16200, 18100, 20000, 22100, 24200, 26500, 28800, 31300, 33800, 36500, 39200, 42100, 45000, 48100, 51200, 54500, 57800, 62300, 66800, 68500, 72200, 76100, 80000, 84100, 88200, 92500, 96800, 101300, 105800 and 110500. The resulting data for each of the centrality measures ranges above 49,000,000 values and this study can hence build on a very large data set to ground observations on.

4. ANALYSIS AND DISCUSSION

We will first start with the results of our random graph model, ERPG, for ASA SLW betweenness centrality to evaluate what kind of patterns might be expectable by human shaped models of regional scale and polycentric urban morphology (Figure 4:1a & 1b). The EFA derived with four different factors for the ERPG model. These four factors are presumed to cause the centrality patterns to emerge. The diagram in Figure 4:1a and 1b, shows the regression coefficient of each radius for the respective extracted factor (I-IV). Every of the line graph represents one factor and the factor loading of the radius it is influencing. Based on the factor loading one can observe associations of different radii and each factor. This allows interpretations for each of the factors and a collection of measured variables. In the case of betweenness centrality for the ERPG we can observe that almost half of all radii (33,800 – 110,500m) are influenced by factor I. Larger radii show the strongest regression coefficient, this means that factor I can estimate parameters more precise then the remaining factors II-IV. Radii between 6,100 and 33,800m can be associated with factor II, radii between 500 and 6,100m to factor III and finally radii between 100 and 500m are influenced by factor IV.

The fact that EFA derives with these factors and that they form a clear pattern in their rotated factor loadings gives insights into general behaviour of centrality patterns in planar graphs. Independent of how the spatial configuration is structured, there are always shortest paths and accessibility advantaged and disadvantaged locations in the system. However, these shortest

2 The radii selection can be further extended by the following equation: $y = 50x^2$ while the resulting value should be rounded to the nearest hundredths.
paths do presumably not exhibit large variation throughout different radii of comparable distance, but between radii of significantly different distance. This leads to a hierarchy switch of one scale to another, meaning that if a journey takes place between two points on a radius of 1,300 metres and another one on a radius of 1,800 metres these two journeys are more likely to select the same path within the network, than a journey taking place between two points on a distance of 41,800m. Such hierarchy switches between two spatial scales are not sudden, but exhibit a smooth transition. This is visible in the gradual difference of rotated factor loadings. Leading to the assumption that spatial graphs inherently feature best-fit structures or scales for certain distance modes. If this is the case we will find similar structures in human shaped configurations and these structures might exhibit a level of optimisation to each of these scales. This is because human beings as well as other natural processes have mechanism of optimisation embedded into their evolutionary being. Barthélémy (2011, p. 59) has pointed to the existence of such spatial network characteristics as indicator of ‘evolutionary processes’.

Both, the UK and GE model, show strikingly similar pattern in their factor loadings (Figure 4:1c & 1d). The EFA derived with 5 factors for both regions with the same radii association for each of the factors, namely: factor I (48,100 – 110,500m), factor II (22,100 – 48,100m), factor III (5,000 – 22,100m), factor IV (800 – 5,000m) and factor V (100 – 800m). Compared to the results of the EPRG model, the real world regions do feature an additional factor and exhibit a clearer constitution of each factor. This could be an indicator for a hierarchical organisation in human activity patterns that are underlying the shaping process of the spatial configuration and define spatial scales. It has been argued that betweenness centrality gives insights into the location of economic activities (Hillier, 2009), giving one conjecture about the emergence of these spatial scales. Walter Christaller’s CPT (1933) pointed to a hierarchical relationship between different sized urban areas and their respective market spaces. In relation to human activity and movement this means individuals are more likely to engage with everyday goods in local markets and rare goods in higher hierarchies. In reality this implies that grocery shopping
is more likely taking place in a local neighbourhood, while specialised services such as the service of a lawyer would benefit being situated at centres of higher hierarchy, as they need to extend their market area in order to suffice the need of frequent customers. We can make the presumption that certain activities take place more often than others, so is the daily commute to a workplace inherent part of the majority of the population, while for example the activity of buying a new electrical goods less so. If these repeated everyday patterns of human activity have an impact on the spatial organisation of societies in a way that an optimisation process shapes the spatial configuration in such a way that these repetitive everyday activities are more effectively distributed through the system, then they might be legible through spatial scales. Moreover, the spatial product of this process will have an impact on the possibility of future activities and subsequently influence the former. One could hence start to make assumptions of the nature of these extracted spatial scales.

If we compare those radii that the derived factors (spatial scales) predict the strongest, with those radii predicted by Christaller’s CPT for different market areas (Table IV), it becomes possible that there is a relationship. The found factors form a strong similarity with the defined radii of Christaller’s CPT. Three of the five derived factors exhibit estimate parameters on exactly those radii, that Christaller estimated for each of his central place hierarchies. An exception form very local centrality patterns (factor IV and V), this might be because smaller centrality pattern are stronger influenced by cultural process then they are by economic activity. Whereas three of Christaller’s seven central place types can be explained through the derived factors, four remaining seem not to be expressed through the EFA. However, with regards to the randomised graph ERPG model, we have already gained insights into the inherent scales embedded in planar graphs and only four of such scales emerged. This might indicate that the remaining centres are not expressed enough to form independent spatial scales. If one follows this assumption it is worth considering the intersection area of each of the latent centralities as points of interest, these intersections are points that can load to either of the two factors. Table IV (light grey radii) include additional sub category of potential spatial scales between the found factors. Again we find rather strong similarities with the distances in Christaller’s CPT and the derived factors.

<table>
<thead>
<tr>
<th>Latent centralities</th>
<th>UK Region</th>
<th>GE Region</th>
<th>Market Radius (m)</th>
<th>Christaller Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighbourhood</td>
<td>200</td>
<td>200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>City</td>
<td>1,800</td>
<td>1,800</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td>4,000</td>
<td>Markort (M)</td>
</tr>
<tr>
<td>Between City/Metro</td>
<td>6,100</td>
<td>6,100</td>
<td>6,900</td>
<td>Amtsort (A)</td>
</tr>
<tr>
<td>Metropolitan</td>
<td>11,300</td>
<td>11,300</td>
<td>12,000</td>
<td>Kreisstadt (K)</td>
</tr>
<tr>
<td>Between Metro/</td>
<td>22,100</td>
<td>22,100</td>
<td>20,700</td>
<td>Bezirkstadt (B)</td>
</tr>
<tr>
<td>Inter-Regio</td>
<td>33,800</td>
<td>33,800</td>
<td>36,000</td>
<td>Gaustadt (G)</td>
</tr>
<tr>
<td>Between Inter/</td>
<td>45,000</td>
<td>45,000</td>
<td>62,100</td>
<td>Provinzstadt (P)</td>
</tr>
<tr>
<td>Intra-Regio</td>
<td>105,800</td>
<td>105,800</td>
<td>108,000</td>
<td>Landstadt (L)</td>
</tr>
</tbody>
</table>

Table 4 - Comparison of the betweenness latent centrality structure with Christaller’s central place system and their respective scales.
These findings indicate that regional morphologies might indeed be able to give insights into the economic processes and human activity pattern that are behind their formation and that Christaller’s theory can to a certain extend explain the spatialisation of the two European regions. Very little has been said so far to the actual spatial configurations that the different factors produce. Following the strategy proposed by Serra and Pinho (2013) one can visualise each factor through their respective loadings. Figure 5 illustrates such a loading plot for each factor for each of the three models, UK, GE and EPRG. The factors include loadings at different intensity for each segment and are hence able to illustrate a rich pattern. Here, only loadings above a standard deviation of 2.0 are highlighted in red (Figure 5). This way of visualisation will increase the distinctive difference between each factor and help interpretation of their morphologic nature. With view to Figure 5, the observed pattern that was observable in the rotated factor loadings is now mapped on the respective spatial network. Again, both regions UK and GE are showing very comparable pattern on all five factors. The EPRG model seems to be comparable to the factors II – V of the UK and GE models, however, it lacks a spatial pattern that is comparable to the first factor of the real world models. While the radii that can be associated with both first factors are similar (ERPG: 33,800 – 110,500m and UK & GE: 48,100 – 110,500m), the actual morphology seems much more comparable to the second factor of the real world cases. With regard to each spatial scale (factor I – V) of both real world regions one can observe how each scale features larger distances between intersecting nodes. This might be an indicator for scaling effects of optimisation processes embedded in human activity. A view on a zoomed in section will highlight how human shaped networks differ to a randomised graph (Figure 6).
Figure 5 - Latent centrality structures for angular segment analysis segment length weighted betweenness centrality. EFA loadings for each factor and case with values above a standard deviation of 2.0 highlighted in red.
Figure 6, gives a direct comparison of the differences between the real world networks and the ERPG. Real world networks exhibit spatial scales that are characterised by long linear cluster of lines. The fact that each scale exhibits such linear networks is a strong indicator for an inherent optimisation processes. The ERPG on the other hand shows comparable line cluster, whereas their morphology differs significantly. Here the spatial scale pattern is more zigzag in nature (Figure 6:1c & 1f). This is because the network simply does not feature straight linear networks, which seems to be a much more efficient distribution of flows through the network. The economic spatial distribution of market centres and a presumed optimisation process seems hence to be legible in the emergent spatial scales. This points to a much more complex relationship between economic activity and spatial configuration than the space syntax concepts of ‘global’ and ‘local’ scales suggest. Moreover, the finding point to the constraints and problems a ‘one city’ theorisation produces. Without considering surrounding cities and their hinterland of any urban area, a full picture of its spatial morphology will not be possible. The third factor (Figure 6:1a & 1b) exemplify this strong intercity relationship. Each of the cluster in factor III comprise of several cities, it stays out of question that this pattern cannot be observed with a focus on one independent city only.

What one should seek instead of employing the dichotomy of ‘local’ and ‘global’ is to unveil the inherent spatial scales hidden in each network by investigating a large array of different radii and extracting latent centrality structures. Differently to Christaller’s CPT, what the findings cannot confirm is the hierarchical configuration he theorised. It seems that his core notion of the distribution of centres seems reasonable while the actual network this hierarchical distribution generates is of more complex nature than his (Figure 1:1d). The morphology of the found spatial scales point to a much more complex pattern and relationships between cities and their hinterland more recent theories have argued for (Sassen, 1991; Taylor, 2004). Polycentric urban regions are particularly characterised by this complex spatial relationships.
This poses challenges for urban policies trying to address change on local levels, because if these strategies do not comprehensively understand the spatial reality of cities as intrinsically linked to different spatial scales and their surrounding urban areas the outcomes might have a very different effect than set up in the aims. Although this research has started from the point of view of the region, it is believed that these findings have a strong informal character for any analytical investigation interested in understanding the city. However, further research is needed to compare the found spatial scales to large-scale data of human and economic activity. If such investigations can support the relevance of these spatial scales they can be appropriated to effective planning tools.

5. CONCLUSIONS

Regional analysis in the field of space syntax is still in a developing stage. Only very few studies have dealt with the scope of a region in a systematic manner. This is not only due to the difficulties researchers are facing in the construction of high-resolution models, but also due to a lack of theorisation of the very entity. Difficulties do also arise in the attempted application of space syntax concepts that are developed in the context of independent cities. Instead this study tried to link concepts of quantitative geography to overcome this difficulty through an initial sketch of the concept of spatial scales. The findings supported the need for a revision of the theorisation of the concept of ‘global’ and ‘local’ in light of space syntax analysis towards a multi layered latent centrality structure of spatial scales.

This study shed light on centrality pattern in polycentric urban regions and random planar graph networks. The analysis compared 49 different betweenness centralities pattern through an exploratory factor analysis and derived with 5 different factors. The morphology of real world and random networks share similarities in latent centrality structures, but are very different in their morphology. These 5 latent centrality structures are theorised as emergent spatial scales by employing Walter Christaller’s central place theory and Erik Swyngedouw’s theory of scales. Such spatial scales are presumed to be inherent to human shaped spatial networks, as they are the product of repetitive human activities and primarily informed by economic processes.

The comparison of human shaped networks to a random planar graph has pointed to an optimisation process that might underlie the formation human networks in general and spatial scales in particular. The findings in both real world regions pointed to a much richer pattern than the one sided hierarchy described in Christaller’s central place theory and unveiled a complex intercity and interregional network that is shaped and reshaped over time. Further research is needed to investigate whether the found spatial scales have relevance in a socio-economic context and can hence be of use to inform regional policymaking.
REFERENCES


6. APPEDNDIX

1 ASA Closeness Centrality Outlier Detection

In this paper we have applied angular segment analysis on closeness centrality in a regional context. There is one problem arising from such an application. There are some few cases of high values cluster in areas of low urbanisation where lower values would have been expected. This is particularly the case on small radii (100 – 2500m), but measureable up to a radius of 5km in the investigated cases. One can compare this effect to a similar problem that Hillier et al. (2012, p. 191) were facing when introducing normalised least angle choice. The problem seems to be related to long linear segment structures or cul-de-sacs (Figure 1: 1b). Such linear structures and dead ends are very common for rural or less-urbanised areas. Highway systems also exhibit this effect. Because partial urbanised areas and rural structures are very common in large cities and in intrinsic part of regions, it is necessary to detect such outlier. While the majority of outlier cases can be identified by visual comparison. Some cases are outlier in lower value ranges and are difficult to identify as such visually. These exceptional cases can only be identified through a comparison with values of their immediate surrounding segments and make it difficult to clean the data manually. However, all segments with unexpected high value share a common characteristic, namely very low total depth (TD) values in relation to the value of closeness centrality (CC). This allows an objective reproducible method to identify outliers, even in cases where a visual comparison of the data would have not allowed detection. This relation between TD and CC allows us to equation a straightforward way to detect outlier in ASA closeness centrality values. By adding the constant of 3 to CC and TD and subsequent dividing the logarithm of CC by the logarithm of TD of the respective radius, one arrives with a new set of values.

\[ \text{CCTD} = \frac{\log(\text{CC}+3)}{\log(\text{TD}+3)} \]

In the case that the new value is equal or above 1 the segment can be considered as outlier. Figure 1: 1a shows a scatterplot that visualises this effect. All values on the right side of the red cut off line can be considered as outliers, whereas the distance to the left indicates the amplitude of the outlier effect.


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A CONFIGURATIONAL STUDY OF SOCIOSPATIAL SEGREGATION IN THE METROPOLITAN REGION OF FLORIANOPOLIS, BRAZIL

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ABSTRACT

Several classical studies of urban phenomena such as socioeconomic inequality and spatial segregation adopt the “concentric circles”, or center/periphery model to characterize locations in urban space, according to which distance to CBD is the main determinant of high and low income classes positions. Contrasting to this coarse-grained view of the city, configurational analyses allow us to identify details in the street level, revealing how the urban fabric is connected and what are the roles of each space in several scales concerning both its proximity to all other spaces and its potential to channel flows between other pairs of spaces. In this paper, we examine the relationships between socioeconomic inequality and the position of different socioeconomic strata in Florianopolis’ Conurbation Area (FCA). We build a multi-dimensional Socioeconomic Index from the 2010 Brazilian Census data and contrast it with configurational properties of the grid using the Theory of Space Syntax and its main measures (Integration and Choice). Several recurring patterns were identified, both at the global and local levels. Results show that more privileged groups tend to occupy areas that are highly accessible both in terms of Integration and Choice, but areas with the highest values in these measures are occupied by the cohorts immediately below. Despite higher global Choice averages, we found that upper cohorts tend to avoid locating themselves directly on main streets or highways, preferring, instead, a more inwards oriented location in relation to the foreground network. That seems to express a strategy which balances relative isolation – avoiding the negative effects of high intensity traffic such as air and noise pollution – with easy access to the city center. In the local level, grid discontinuities and the prevention of mutual visibility are the strategies utilized (often simultaneously) to separate two contrasting areas that, otherwise, are located near to each other.

KEYWORDS

Socioeconomic Inequality, Sociospatial Segregation, Space Syntax, Urban Configuration, Socioeconomic Index.

1. INTRODUCTION

Brazil’s urban development was deeply influenced by the contradictions of the city (Freyre, 2014): the rich and the poor, the dominant class and the popular strata, the lofts and the huts, the gated communities and our indigenous version of the shanty towns, the notorious and infamous “favelas”. According to Villaça, “Brazil’s biggest problem is not the poverty, but the inequality and injustice associated with it” (Villaça, 2012, p. 44). Understanding Brazil’s society...
implies comprehending the phenomena of socioeconomic inequality, to the same extent that comprehending Brazil’s urban space – ethereal drama stage of class struggle and its contradictions galvanized in concrete – implies comprehending the socio-spatial segregation.

Quite a few theories on the relations between society and urban space – and consequently about socioeconomic inequality and spatial segregation – approach the subject from the classic point of view of concentric circles – or center/suburb. This perspective took shape in the beginning of the 20th century, with the School of Chicago, and it still reverberates in many socio-spatial studies. However, the generalized description of the urban space and the neglect of the socioeconomic relations of society (Harvey, 1980) direct us towards an ideological comprehension of urban phenomena, naturalizing urban injustices like the socio-spatial segregation (Gottdiener, 1997).

To this perspective of social production, we propose adding the study of spatial configuration, that allows us to describe and comprehend the locations within the urban space in a more refined way, revealing in different spatial scales the possibilities – and probabilities – of encounter between different groups in their daily movements. Configurational analyses help us put in evidence systems of permeability and barriers to movement – and, by consequence, proximities and distances – between spatial locations in a much more precise way than the descriptions traditionally adopted by the theoretical models that aim to explain segregation. Therefore, while most studies on spatial segregation consider the urban space in a wide and shallow spectrum, the configurational analysis uncovers more details about it, while considering the way the urban fabric is connected.

Our research aims to understand the relation between socioeconomic inequality and the location of the socioeconomic strata of the population of the Florianópolis’ Conurbation Area (FCA), located in the south of Brazil, by investigating the distribution of these strata and their relation with the urban space configuration. In order to do so, we characterized the FCA with a Socioeconomic Index and described its configuration through the theory of Space Syntax and its main categories, Integration and Choice.

1.1 FLORIANÓPOLIS’ CONURBATION AREA (FCA): BACKGROUND

Florianópolis’ Conurbation Area (FCA), for the purposes of this study, encompasses four municipalities (Florianópolis, the state capital, São José, Palhoça and Biguaçu). It is unique in the Brazilian urban context, with its invaluable natural heritage – highly attractive to tourists, and also physical basis for the production and consumption of its urban space – the insular condition of a significant part of its territory, and the deep marks in space and local culture brought about by Azorean immigrants.

Initially, the main foci of development were concentrated in small localities around the Island of Santa Catarina, in which fishing and subsistence agriculture were the main economic activities. Travels were made almost exclusively by the sea, with few and far between terrestrial paths sinuously connecting the “freguesias”, as these localities were known (Reis, 2012). From 1970 onwards, with the construction of BR-101 and BR-282 federal highways, the four municipalities experienced an intensification of their urban fabrics intertwining, marked, among other things, by the concentration of state investments in the insular (and richer) portion (Sugai, 2015).

According to Sugai (2015), these investments were directed to those portions of the Island in which the upper classes had direct interests. This way, a ‘structuring and interconnection axis was formed between the residential areas of the elites and the neighborhoods where they intended to expand their residential and summer areas’ (Sugai, 2015, p.148). In spite of these actions to improve accessibility, nowadays FCA’s grid is among the most segregated in the world (Medeiros, 2013), not only as a consequence of its environmental conditions but also because of historical, cultural and political aspects.
2. DATASETS AND METHODS

The method of the research articulates two specific objectives: the characterization of the socioeconomic reality of the FCA by a Socioeconomic Index, and the characterization of the FCA’s urban configuration through Spatial Syntax Theory. From the output of these descriptions, we compare the location of socioeconomic strata of the population with its configurational characteristics.

The Socioeconomic Index draws from the work of Jannuzzi (2001) and Genovez (2002), and uses data from IBGE’s Demographic Census Research (2010), which means that the territorial unit adopted is the Census tract, totalizing 1216 sectors in the FCA. It pursues some desirable key features, such as reliability, comprehensiveness, intelligibility, data gathering feasibility, updating periodicity, and spatial resolution.

The dimensions upon which the index was built are: Income, Education, Housing, Infrastructure and Surroundings. Each of these dimensions was described through one or more variables, as shown in Table 1, according to its availability in IBGE’s Census and preliminary analyses about redundancies. The weight of each dimension was determined through the AHP method, building on the experience and input of the authors and a team of experts working in the master plan of one of the cities of the FCA.
<table>
<thead>
<tr>
<th>Socioeconomic Index</th>
<th>Dimensions and Variables</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>Household average income</td>
<td>0.482</td>
</tr>
<tr>
<td></td>
<td>Percentage of individuals earning less than US$560.00 (monthly)</td>
<td></td>
</tr>
<tr>
<td>Literacy</td>
<td>Percentage of literate heads of households</td>
<td>0.146</td>
</tr>
<tr>
<td>Housing</td>
<td>Number of bathrooms per residents</td>
<td>0.198</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>Percentage of residents with own bathroom or access to public sewer system</td>
<td>0.111</td>
</tr>
<tr>
<td></td>
<td>Percentage of residents with access to public garbage collection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of residents with access to public electricity system</td>
<td></td>
</tr>
<tr>
<td>Neighborhood</td>
<td>Percentage of residents with access to public street lighting</td>
<td>0.063</td>
</tr>
<tr>
<td></td>
<td>Percentage of residents in paved streets</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of residents in areas free of sewer exposure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Percentage of residents in areas free of waste accumulation</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 - Dimensions, weights and variables of the Socioeconomic Index.

Thus, five socioeconomic cohorts were classified (A, B, C, D and E), with cohort A referring to better socioeconomic conditions, that is, higher household average income, percentage of individuals earning less than US$560.00 monthly near to zero, higher percentage of literate heads of households, houses with better infrastructure conditions and neighborhood with urban facilities and services. On the other hand, cohort E represents the opposite conditions to those of cohort A.

The configurational characterization of the FCA's urban space was made through an angular analysis of segments consisting in global Integration (Rn), local Integration (R1200m, roughly equivalent to a 15 – minute walk), global Choice (Rn) and local Choice (R1200m). After obtaining the configurational and socioeconomic information on the FCA, the data were exported to a geoprocessing software (QGIS), allowing the superposition of the information, and the visual and statistical analyses to be presented below.
3. RESULTS

3.1 PRELIMINARY OBSERVATIONS

The distribution of the socioeconomic cohorts throughout the conurbated area shows that the highest strata is predominantly located in Florianópolis, especially in its insular portion. We can also confirm the concentration of cohort A along the direction that Sugai (2015) called the “privileged access routes of the upper classes”, extending from south of BR-282, along Av. Beira-Mar Norte, and heading north to Jurerê and to the east towards Lagoa da Conceição (Fig. 1).

Reciprocally, sectors with worse socioeconomic conditions are primarily located in the peripheries of the conurbation, particularly in the mainland and in the northeast and south / southeast of the Island. The situation of Biguaçu, the poorest of the municipalities, is especially problematic, with almost all of its sectors belonging the two lowest socioeconomic cohorts (“D” and “E”). On the other hand, it is also possible to see some of these strata located in central areas, although in a significantly smaller number.

Configurationally, we see a more intensified grid at the insular and continental peninsulas in the central portion of the system, where the most integrated segments are located. Outside of this Integration core, there is a rather dispersed grid pretty much everywhere else, resulting in several disconnected neighborhoods in the periphery. This is a consequence of three main factors: the extremely complex and varied environmental conditions, the previous rural subdivision, and the substitution of a protourban structure based on naval flows by another based on a rather precarious road system (Reis, 2012). In the mainland, however, this situation is somewhat less severe.

An examination of the global Choice values (Fig. 2c) shows that the foreground network of this central core is formed by rings that structure more local areas but, beyond them, it is constituted mainly by expressways that divide, more than integrate, the urban tissue. Because of a near tree-like structure, several of them are, for practical purposes, the only connections available between important localities. In the mainland, however, there are a greater number of situations in which the foreground is in close proximity to the background, creating areas in which it is easy to access the former from the latter, and also affording a greater variety of possible paths.
3.2 SOCIOSPATIAL ANALYSIS: GLOBAL RADIUS

3.2.1 GLOBAL PATTERN #1: PRIVILEGED CLASSES IN MORE INTEGRATED STREETS

The overlay of the Socioeconomic Index and Global Integration shows a general proximity of sectors in better socioeconomic conditions to more integrated routes. This is the case for the most part, although some of them are located outside of the Integration core, such as “Jurerê” in the north, “Lagoa da Conceição” in the east, and “Pedra Branca” in the West (see Fig. 1 and Fig. 2a). Of these, only the latter is not directly related to an environmental amenity (beach and lagoon for the first two, respectively).

Figure 3 confirms this trend and shows that there is a little drop in global Integration values for the “E” cohort, with highest values in the “A” and “B” ranges (Fig. 3a). Figures 3c and 3d show in more detail the locations of “A” class in comparison to the “E” class, also confirming that the higher cohorts are located in more integrated areas. This suggests that privileged classes tend to occupy areas of the city that are nearer, on average, to the system as a whole, revealing a desire (and capacity) to take possession of the best areas in terms of accessibility (at least as inferred from a configurational and angular point of view). At the same time however, they seem to avoid the most integrated streets of all, probably because of the nuisance supposedly associated with higher number of people and liveliness of these spaces, preferring slightly less (yet still highly) integrated ones.

Figure 3c shows that this average is achieved by a combination of medium-high global Integration values and a relatively narrow range, especially if compared to the “E” cohort. It also shows three distinct clusters: the first (1) is Beiramar Norte, an area along the sea with high global and medium-high local Integration. The second (2) corresponds to planned neighborhoods in medium global Integration and medium-high Local Integration (Jurerê, Pedra Branca and Jardim Anchieta). They represent newer developments that avoided the more central areas but still display a grid-like structure, although the connections to the immediate surrounding tend to be sparse. The third (3) cluster comprises, for the most part, neighborhoods associated with environmental amenities (Praia Brava, Canto da Lagoa da Conceição and Cacupe). One
important exception, in that it is not close to an important environmental amenity, is Bosque das Mansões, in the central portion of São José. All of them are poorly connected on a local level, presenting closed communities’ characteristics (or actually being one, as is the case of Bosque das Mansões) and tree-like internal structures, while varying more freely on global Integration values.

By the same token, it is clear that the vast majority of “E” sectors (in red) are located in the more segregated, peripheral and disconnected areas, as can be seen by a visual comparison of Figures 2a and 2b. Although there are spots from the “E” cohort in areas with good integration, this is clearly an exception and not the rule, probably originated by a combination of irregular occupations and the necessity to be close to jobs and other facilities. The numerical analyses provided in Figures 3a and 3b confirm this finding, albeit Fig. 3d shows that the range of locations for the “E” cohort is much larger and nearly encompasses the full range of Global Integration. The image leaves no doubt, however, that there is a significantly higher concentration of locations in the medium and lower ranges.

3.2.2 GLOBAL PATTERN #2: NON-RESIDENTIAL ACTIVITIES IN INTERMEDIARY COHORTS

As expected, there is some coincidence between Integration and the density of nonresidential activities and Jobs (Fig. 2b and Figs. 4b and 4c). The scattergram in Figure 5 shows, however, that higher densities of nonresidential activities are almost never found in the extreme ranges of the socioeconomic index, concentrating very clearly at around 0.5 – 0.6.
From this point, the density of nonresidential activities decrease in both directions. We suggest that this corroborates the avoidance of most integrated lines by the highest cohort, as mentioned earlier. Nonresidential activities are, after all, a source of liveliness, sounds, transit, smells and other inconveniences. Furthermore, this social group is highly mobile and willing to trade some accessibility (nearness) by a quieter surrounding. This, coupled with the next pattern relating to global Choice, guarantees that it will have near optimal locations within the urban system.

In summary, then, we have a situation in which there is a high dependency between the four municipalities and this central area, with especially bad conditions in the “E” cohort case, which is located at the more distant regions of the conurbation. These regions are extremely poorly served by nonresidential activities – not only retail but also important facilities such as bus terminals, hospitals and governmental departments, among others. Consequently, socioeconomic deprivation is made even worse by this combination of locational aspects, especially when we consider their need to access these activities in places far from home and their dependence on a poor public transportation system.

3.2.3 GLOBAL PATTERN #3: PRIVILEGED CLASSES NEAR HIGH CHOICE STREETS – BUT NOT TOO NEAR

Differences in Choice between better and worse off classes are even more pronounced than those of Integration (Fig. 3b). On average, the choice values of the “A” range are much higher, suggesting that they locate themselves in areas at or near streets high in through movement, although, again, the higher values are in the “B” cohort. This proximity, however, does not mean direct contact; in several areas, what happens is that the “A” cohort is near high Choice roads but slightly removed from them. This affords easy access to the road (and, consequently, to the CBD), while at the same time avoids the nuisance brought about by the intense traffic.

Conversely, “D” and “E” cohorts frequently occupy areas immediately adjacent to high global Choice segments. This pattern may be found in several locations, such as State Highway SC-401 (Fig. 6-1), that connects the CBD to the beaches in the North, District of Rio Vermelho, in the Northeast (Fig. 6-2); in most of the extent of Federal Highway BR-101 (Fig. 6-3) and Federal Expressway BR-282 (Fig. 6-4); and State Highway SC-405 (Fig. 6-5). This is the case, however, only when the road has the characteristics of an expressway, but not when it has environmental and sightseeing qualities such as in Beiramar Norte. This pattern also seems to be somewhat weakened by the conjunction with global Integration, since in areas where this measure is high we see more of cohort “C” and less of cohort “E” along the highway (compare the south portion of BR-101 to its central segments, for instance).
This combination of high (but not highest) integration and choice may be regarded as a more accurate description of what Sugai (2015) loosely called “the privileged access route of the upper classes”. It affords the higher socioeconomic classes two kinds of locational advantages: they remain, on average, closer to the rest of the system and – more importantly, judging by the greater differences – closer but not directly adjacent to the streets that carry out important connections in the grid and are on the paths between other locations. This, in turn, is linked to higher presence of commercial activities and microeconomic vitality (Hillier, 2009). At the same time, however, they are able to avoid the negative externalities associated with these factors.

It is remarkable that a purely configurational measure is able to capture this phenomenon so clearly. It shows the power of public investments in transforming the material structure of the city, especially when we compare the original path of the colonial era with the much more straightened contemporary route. Angular minimization seems to have been an active and significant force in this transformation throughout the decades.
3.3 SOCIOSPATIAL ANALYSIS: LOCAL RADIUS

3.3.1 LOCAL PATTERN#1: LOWER COHORTS IN STREETS WITH LOW CHOICE AND INTEGRATION VALUES

This pattern closely mirrors that of their global counterparts, albeit probably for different reasons. While in the global case the low values of cohorts “D” and “E” are related to the low prices of locations distant from the more integrated areas, in the local scale this is not necessarily the case, since there is no obvious reason to assume that locally integrated streets have higher land values than segregated ones. It was not possible to unequivocally identify the cause of this phenomenon, but it is probably due to the tree-like structure prevalent in most of the peripheral areas, coupled with the segregation and low Choice that, almost by definition, characterize areas in the outer portions of any syntactic system. It seems, however, that planned neighborhoods for the upper classes sometimes manage to circumvent this tree-like structure and achieve quasi-grids street systems.

Highly locally integrated areas tend to afford better conditions to the development of local centralities (Hillier 1999; 2009), social contact and better use of the facilities in their surroundings – considering that the radius of 1200m is roughly equivalent to a 15 minute walk. Underprivileged population living in locally segregated areas have these possibilities undermined, adding once more spatial disadvantage to their already difficult situation.

3.3.2 LOCAL PATTERN #2: SEGREGATION BY GRID DISCONTINUITY

The most common pattern in the local scale is segregation by grid discontinuity between adjacent areas with contrasting socioeconomic conditions. There are several examples where misalignments between streets separate areas that are otherwise very near to each other. Such is the case, for instance, of the deprived areas in Morro da Cruz, in the central area of Florianópolis and relatively near to Beiramar Norte (Fig. 8a); Pedra Branca e Frei Damião, in the mainland (Fig. 8c); and “Bosque das Mansões”, a gated community (Fig. 8e). Figures 8b, 8d and 8f highlight the shortest paths between the contrasting areas depicted in the images on the left. It becomes clear that any possibility of interaction in errands and other daily patterns of movement is severely restricted in such situations.

In fact, there is reason to believe that this grid-generated segregation may have important implications in the emergence (or lack thereof) of neighborhood ties among adjacent areas. Not only the flow of pedestrians is impaired, but also of vehicles. What is more, even the routes of public transport systems have to make excessive turns in order to cover a reasonable area. As a result, the copresence (and its possible ramifications, like interaction, familiarity, collaboration, weak and strong ties, etc.) among people from different classes and backgrounds is also minimized.
A CONFIGURATIONAL STUDY OF SOCIOSPATIAL SEGREGATION IN THE METROPOLITAN REGION OF FLORIANÓPOLIS, BRAZIL

Sometimes, but not always, this pattern emerges as a result (at least partially) of topographic conditions. This has the effect of making the disconnectedness more “natural” and, at the same time, hide one community from the other. That is the case in Morro da Cruz and Bosque das Mansões, above, but not of Pedra Branca and Frei Damião. These last two communities, despite having similar values of global Integration, have quite different local Integration. Pedra Branca has a central avenue (Av. Pedra Branca) that crosses its full extent and structures its grid, and is highly integrated in the local scale. It has a tendency to be the seed of a local centrality that, nonetheless, will not be a viable option to the inhabitants of Frei Damião. Apparently, due to the absence of a hill separating both communities, a wall has been built between them to ensure that not even mutual visibility is possible, as can be seen in Fig. 8d. Another wall was built along the interface to the other deprived community in the west. The location and extent of the walls leave no doubt as to what contacts they are trying to prevent.

1 The yellow area to the east of the green portion is also part of Pedra Branca. The classification in the “C” cohort is most likely due to its more recent development and the imprecisions, at this scale, of census tracts.
In the case of Beiramar Norte and Morro da Cruz, despite being in the central area of the island, they have vastly different values of global Integration. The proximity between them was not able to overcome the effects of the highly disconnected and tortuous grid that characterizes the deprived community. Perhaps more worryingly, the local Integration is very low as well, obstructing the emergence of strong spaces for the gathering of its inhabitants and the maintenance of commercial and communal activities.

**Figure 9** - a) Normalized global Integration; b) Normalized global Choice; c) Normalized local (R1200m) Integration; d) Normalized local (R1200m) Choice.

### 4. CONCLUSIONS

The investigation of the spatial distribution of socioeconomic cohorts as described by syntactic measures of grid configuration showed that the classical approach of concentric circles is not a sufficiently accurate model. We found, instead, that the upper socioeconomic ranges seek not only locations near the CDB but also more remote one that, nevertheless, have direct and easy access to the CBD through high Choice streets or highways. This does not mean, as the study revealed, that these cohorts place themselves directly at these streets. Rather, they have a tendency to (self) segregate, mildly isolating themselves from the foreground network while guaranteeing easy access to it. On the other hand, we found that the lower socioeconomic ranges were far more frequently located directly along these routes, at least when they have the characteristics of expressways.

At the local level, when contrasting socioeconomic sectors are close to each other, topography and the road system are often used to disconnect them from each other and thereby decrease the likelihood of casual encounters and copresence in daily activities and movements. The suppression of mutual visibility also appeared as a pattern in these cases, achieved either by topography conditions or by the deliberate construction of walls separating the areas.

The consequence of this scenario of socioeconomic inequality and sociospatial segregation is the likely reduction of contacts with people from different social and urban backgrounds, with the ensuing effect of reduced coexistence and opportunities to exercise tolerance, empathy and negotiation in situations that involve unfamiliar characteristics and social values. Moreover, the
segregation at the global scale restrain the access of the most deprived groups to institutional and community facilities, as well as to jobs and retail. This brings an extra burden on an already underprivileged group, imposing higher commuting times and costs, diminishing their available free time and restricting their capacity to pursue leisure and social activities.
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THE EFFECT OF UNIVERSITY CAMPUSES ON THE SPATIAL CULTURES OF TWO MID-SIZED TOWNS:
A Comparative Study of Nottingham, UK and Eskisehir, Turkey

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ABSTRACT
This study focuses on the effects that university campuses and the presence of students has had on the growth and economy of two mid-sized cities. It examines the extent to which the existence of university campuses affects their local economies, and attempts to define the contribution of students to urban sustainability. Students are discussed in the context of university cities as examples of ‘creative cities’, so attractive to urban decision-makers. The university itself is presented as a ‘creative industry’, an indicator for socio-economically sustainable cities. The research then describes how universities manifest their roles in the public realm in a spatial way. To do so, two case studies are presented, Nottingham (UK) and Eskisehir (Turkey), which are similar in terms of demography and the location of their campuses. The study investigates both the relationship of campus locations with their surrounding areas, and the relationships that students have with their cities and local populations, using historical and contemporary maps, land use surveys, on site observations and questionnaire results about user activities.

The research examines the historical development of the university areas in the case-study cities in terms of their spatial structure and social morphology. The campus areas are divided into three categories according to their location in the city: the ‘city centre’, ‘edge of the city’ and ‘outside of the city’. The locations of student accommodation are also mapped. The main analysis explores the emergent relationships of campuses and student areas to urban centres, using space syntax measures of network accessibility and area users routes. The aim of the study is to better grasp the relationship between campus and city by considering the presence and the distribution of university buildings and students in urban space in historical perspective. It highlights a better understanding of how student populations affect the socio-economic development of cities, can contribute to a better comprehension of the ‘creative city’ and the ‘sustainable city’.

KEYWORDS
movement of economy, university campus, sustainable city, student, Space Syntax
1. INTRODUCTION

This research will present comparative research based on the analysis of two similar kinds of university towns: Eskisehir in Turkey, and Nottingham in the United Kingdom, in order to explore the socio-spatial impacts of the universities on the towns and the different ways in which students interface with the city. According to Coulson et. al. (2011, p.1-39), the history of higher education has evolved through successive phases to take its present-day form. The first universities, founded in the 1100s, were based on prototypical forms of fraternal organization in Bologna, Paris and Oxford. Professorial fame attracted many students to learning centres across Europe and they gathered in scholastic societies comprised of similar kinds of merchant guilds and artificers which built themselves up as the ‘prime sponsor of learning’ inside of their respective towns and cities over two centuries. During this period, universities were rooted in urban centres and formed the constitution of their host city. However, the early universities didn’t have specific buildings. After the student population began to increase and internal migration abated, universities started to obtain property in various parts of their respective cities. As the Renaissance period progressed from c.1400, universities began to take possession of appropriate academic quarters. The omnipresence of physical universities in urban locations started to represent the town’s character. Oxford and Cambridge were the first examples of students lodging with a town’s people and, following this, the proliferation of ‘halls’ and ‘hostels’ occurred. According to Neuman (2003), since the eighteenth century, university emplacement began to engage with certain places and this settlement with its introverted learning community and its permanent spatial organisation created the term ‘campus’ (Yaylali-Yildiz et. al., 2014). From the second half of the nineteenth century, new social, economic and intellectual impacts caused an enormous increase in the number of university buildings. The structures of universities in this period are not surrounded by walls, isolated in the countryside, or introverted. Universities have a large monumental city centre composition and universities have settled for symbolic capitals or giant single structures that represent the new university buildings. Substantial cultural advantages have accrued through the synergy of the city and university. After World War II, student enrolments saw rapid increases and these substantial changes reflected the pattern of university buildings and designers were determined to represent the ‘ideal community in a microcosm’ as a ‘whole cloth’.

The chronological development of a university’s environment is related to changes in teaching, research, social ideologies, mobility, and architectural fashions. Each historical era has had its own effect on campus designs and their relation with their surroundings. This means that the year a university was founded, geographical, cultural differences and administrative approaches make changes to its architectural form and relationship to the city in each case.

Landry (2008) argues that embedding creativity into the city’s ‘genetic code’ is the key factor behind creating a successful urban creative milieu through the use of non-traditional, innovative approaches to urban development. According to him, a ‘creative milieu’ is defined as a place that is a part of a city, an entire city, or a region, rather than a localised building cluster. This kind of milieu is a physical arrangement where a creative group of intellectuals, artists, power brokers, entrepreneurs, social activists, administrators, or students can operate in an open-minded and cosmopolitan context within a physical setting, wherein the creation of new ideas, products, artefacts, institutions or services might be facilitated by face-to-face interaction. As a result of this diverse relationship of social and spatial networks, economic success occurs. However, creativity is not a measurable quality because it is not only a physical concept, but also contains social network. Due to this fact, this study will primarily focus on the spatial effects of universities.

Space Syntax theory is a useful means through which to explore how universities shape and are shaped by the spatial morphology of cities over time. Hillier (1996) advances two theories linking spatial form with social form: the theory of ‘natural movement’ and the theory of ‘movement of economy’. Griffiths (2014) notes that in Hillier et al. (1993)’s ‘natural movement’ proposition the spatial configuration of the urban grid itself generates ‘attraction inequalities’ so that more integrated urban spaces generate greater levels of movement on a ‘probabilistic basis’, prior to the consideration of land-use attractors. The theory of the movement economy
proposes that land uses profit from a ‘high rate of movement cluster’ in highly suitable locations at a premium cost and, as a result of this, less movement finds an appropriate position in the network. High-movement spaces that characterise urban centres become more generative of diverse social relationships and residential areas become more conservative. This different ‘pervasive’ centres’ system is characterized by the distinction between ‘foreground (retail) and background (residential)’ networks that produce emergent intensities of movement across all scales of the urban grid (Griffiths 2014, Hillier and Vaughan 2007, Hillier 1999).

In addition to these spatial theories of movement Hillier (2015) defines three factors important to city sustainability: energy, society, economics, and in addition to those, a fourth one: creativity. The creativity of the city, according to Hillier, largely explains why cities exist – as spatial networks to create and control social networks. The university campus therefore is an actor reproducing the social network of a specific academic ‘guild’ and also has physical embodiment in the spatial structure of a city. Micro-to-macro scale space syntax analysis exploring the relationship between the foreground and background networks of the city can help us to understand how different kinds of university building are situated to facilitate or restrict socio-economic interfaces with the larger urban area.

In the Dictionary of Human Geography (Castree et. al., 2013) ‘studentification’ is defined as residential neighbourhoods, which are dominated by student households causing social, cultural and environmental changes to previously established residential communities. For the revitalisation of North American mid-sized city downtowns, residential land use enhancement – such as might be provided by student accommodation – was suggested as a solution by planners (Charbonneau et. al. 2006; Birch 2002; Gratz and Mintz 1998). Jane Jacobs (1961) stated that safety and liveliness are key factors for sustainable cities and suggested that housing in the city centre might be helpful to increase the presence of people on the street. Retail and service facilities are the other constituents of a lively urban society (Charbonneau et. al. 2006; Bunting et. al. 2000; Hudnut 2000). The solution of planners was that the presence of residential populations might encourage and enhance pedestrian movement, and consequently, increase safety and commercial development around the area; thus, mid-size cities might use the university community as an advantage to revitalise some parts of the city and associate this with student housing (ibid). Many different elements influence the housing selections of students such as financial power, their flexibility, distance from campus, accessibility, co-renters etc. therefore the complexity of housing decisions affects the spread of students to the areas and city (ibid). For this reason, conducting a research about this topic become difficult.

Henri Lefebvre (1991) argued that ‘social space is social production’ and that where there is change in spatial relations there will be a change in social relations. Chao Ye et al. (2014) argues that the production of space theory provides a perspective which connects society with space and time, and helps to understand land-use and cover change (LUCC) as a social, rather than simply an economic, process. Three types of time scale interact with LUCC policies and each has a different effect on LUCC and production of space (ibid). In general, spatial representations of LUCC reflect cultural heritage or transitions over the long term (more than 10 years); more economic and political changes are reflected in the medium term; and social change or everyday life is externalised in the short term (ibid). The development of a university town is a ‘complicated, dialectical, and interactive process between time, space, and society’, because a university is a place where knowledge is produced, but this production cannot be separated from the specific context of time, space and society. According to Chao Ye et al. (2014), this process is related to urbanisation and LUCC.

A campus refers to a social and spatial aggregation that has influence on the production of social space with various kinds of parameters. Space Syntax has been proposed as a theoretical and methodological framework for investigating the local to global effects of campus-space in cities. In order to understand the relationship between movements of clusters and land use, the identification of whole structure characteristics about residential and retail areas, which are genetic codes for cities, have been provided by this theory.
2. CASE STUDIES AND HISTORIC BACKGROUND

The main aim is to understand the general effect that university campuses have on their surrounding areas and how these areas find their place within the structure of a city. To meet this purpose, case-study areas have been chosen according to their similarities and the variety of campus locations from two different countries. The primary similarities are campus numbers and locations in a city, and general geographical, natural features, the city's location in the country, and transportation features.

Eskisehir is a city located in the centre of Turkey and the population of the city increased rapidly between 1950 and 1985. In addition to new industrial developments, during this period, higher education facilities had great progress and the city's land use was affected deeply (Ilgar, 2008). The city hosts two universities: Anadolu University, founded in 1982, and Osmangazi University in 1993. AU has two campuses, which are Yunus Emre, the oldest campus in the town, and Iki Eylul, which was opened in 1998 (Figure 1).

Figure 1 - Campus locations and general features of Nottingham (above) and Eskisehir (below) (Sources of Nottingham: based map; Bing aerial and roads, green areas and waterways; EDINA Digimap, Sources of Eskisehir: based map; Bing aerial, roads, green areas and waterways; Geofabrik)
The city of Nottingham is located in the East Midlands, in central England. Two universities are located in Nottingham: the University of Nottingham and Nottingham Trent University. The University of Nottingham’s roots are in 1798 and in 1881, the school had its first permanent building, which is now Nottingham Trent University’s building in the city centre. The university moved from its present main campus (University Park) in 1928 on the outskirts of the city. Overall, in Nottingham, the university has University Park, the Medical School, and the King’s Meadow (2005) and Jubilee Campuses (1999). The second one, Nottingham Trent University, was originally founded in 1843, with a different name and after a few formations in 1992 it was initiated. Currently, it has two different campuses, which are known as City campus and Clifton Campus (Figure 1).

3. SYNTACTIC ANALYSIS OF CITIES AND STUDENTS’ LIVING PLACES

The spatial analysis mostly focuses on how university campuses integrate and connect to the whole urban system and how they relate to the movement patterns of urban structure as an attractor, investigating the relation between spatial network sand potential of movement. Choice and integration measures, which are through-movement and to-movement, are the major means of analysis to indicate potentiality of surroundings (Hillier and Hanson, 1984).

Campuses are divided into three types: city centre, edge of the city, and outside of the city. ‘Outside’ campuses’ integration values are not high like the other campuses but still integrate with the city. Anadolu University Yunus Emre campus in Eskisehir and Trent University in Nottingham are city campuses, Osmangazi University and the University of Nottingham are edge of the city, and Iki Eylul campus of AU and Clifton campus of NTU outside campuses. After explaining the relation of the universities with their own towns, each case will be compared.

Figures 2 and 3 demonstrate the normalised angular choice analysis for two case-study cities in radius n, which refers to the potential of route choices of each segment in global scale. It illustrates the least accessible segments in blue and with high potential of accessibility in respect to the whole system in red. In Nottingham, all university campuses link to a system with a street that has a high value, including the outside campus, namely Upper Parliament Street and Mansfield Road in the City area, Clifton Boulevard and Derby Road in the Lenton area, and Clifton Lane in the Clifton area. In Eskisehir, the edge and city centre campuses have similar characteristics, however, the outside campus does not have as high value as the others. In Eskisehir, Ismet Inonu Street and Universite Street in the Tepebasi area and Ataturk and Genclik Boulevards are identified as high streets. In addition, around 1 km distance, that is suitable distance to walk, surrounding area of campus boundary and campus’ own structure was selected to evaluate.

For Eskisehir, results show that the area around the city centre campus has a good integration with the city (Table 1). OGUM campus area is less integrated compared with the whole system. The reason for this is not only related to integration with the neighbourhood, it is also associated with the university’s connectivity. The third, Iki Eylul, has almost the same integration value as the average of the whole system according to global integration value, but here, numbers of segments are lower than the others. In addition, the connectivity of the whole system with each area has different relations, for instance, OGUM campus is slightly higher (approximately 0.2 more) than the outside one and the central campus has the highest connectivity value.
THE EFFECT OF UNIVERSITY CAMPUSES ON THE SPATIAL CULTURES OF TWO MID-SIZED TOWNS: A Comparative Study of Nottingham, UK and Eskisehir, Turkey

City and UNUP areas are significantly close to the whole model's value. It is significant that these areas provide the wide range of spatial syntactic values and refer to diverse types of urban space. On the other hand, Clifton area values are restricted within a narrow range and the maximum value is much lower than in other cases.

The wide-ranging differences between minimum and maximum values of area refer to duality structure of the city and the diverse characteristics of it. The duality structure of the city depends on patterns of local differences and global similarities that describe settlement forms (Hillier, 2001). Socio-cultural life creates one pattern, which is domestic life and socio-economic activities, while trade generates another. Therefore, less integrated areas generated by local process and refer residential site. Students are the agents who effect to flow between those patterns.

Normalised integration and choice combination analysis shows that student accommodation is located mostly in streets that have a warm colour at the higher end of the integration spectrum (Figure 4). This distribution is especially visible at radius 800 and 2000. Radius 800 is associated more with local scale, that is a distance walkable in 5-10 minutes, while radius 2000 is a suggested measure for urban-scale vehicular movement. In the Eskisehir analyses, the blue (segregated) areas are not preferred by students, while the most significant thing is that accommodation is clustered around high integration streets at a local radius. Student households are not detected in the south part of the city centre campus area, and the west part of the edge campus area even has a good value in global scale. It shows that students prefer to live in areas which are suitable for short travels on foot or by vehicles.
Figure 2 - The spatial normalised angular choice analysis at radius $n$ of the whole system of Nottingham.
Figure 3 - The spatial normalised angular choice analysis at radius n of the whole system of Eskisehir.
Nottingham city centre campus and edge campus have high integration, however, the outside campus area has a lower average than the whole system (Table 2). NTU City area values are significantly more than all others. The minimum and maximum values of NTU selected segments according to student accommodation’s entrance normalised choice and integration combination values show that student accommodations in 2 km distance from city centre campus in Eskisehir are located significantly integrated segments and also have high choice values in local to global scale (Figure 4). On the other hand, the accommodation around OGUM campus also has high value at a local and intermediate scale but average values are lower than the model’s at a global scale. In Nottingham, by contrast, the highest percentage of student households are located in accessible and ‘easy to pass’ areas at a local, intermediate, and also global scale, especially in Lenton (Figure 4). Students relatively occupied the city centre in both cases and also local and intermediate scales come to the forefront for both.

4. COMPARATIVE ANALYSIS

In order to explore the range of different socio-spatial interfaces between university buildings and the city in a greater depth, focusing on daily life activities and user types in student areas (Figure 4), user routes and activity questionnaires were conducted on high streets in both case study cities: Mansfield Road and Upper-parliament Street (UK) and Universite Street (Eskisehir) for city centre campus types and Derby Road (UK) and Genclik Boulevard (Eskisehir) for edge of the city campus types. These streets are intersections of foreground and background network of the cities according to syntactic analysis – that is they are local-global structures. Participants in the surveys were asked to draw their destination routes from start point to end point on a map. The kinds of user activities in selected areas were revealed through asking participants’ reasons to be in each location at that time. Participants, who are pedestrians, were selected randomly in the streets and divided into student or non-student groups and the approximate user percentage was specified. The survey was conducted on more than 25 people for each case during working hours (starting at approximately 11.00 am and ended at 7.00 pm). The study was only focused on pedestrian behaviour since it assumed that this travel mode has more contribution for casual encounters, commercial and daily life activities in which students participate. Segregated campuses have not been taken into account since there is not any shop or activity centre in both towns.

According to the results (Figure 5), participants’ reasons for being there are mostly related to the university and a few non-student participants also selected this option. Therefore, the university is an attractive element for users of these areas. It is notable that for each area except the city centre campus in Nottingham, numbers of students has highest percentage of participants but even then the percentages are very close to each other in Nottingham city centre (57% non-student and 43% student).

At the city centre campus, shopping, eating, meeting or visiting friends/family, and drinking coffee/tea are the activities that have the significantly highest. Dominant activity types at edge of the city campuses are not similar to those in the city centre. In the case of Eskisehir, university is the primary reason for many of the users (31%) but for Nottingham it is relatively low (14%). Meeting or visiting friends/family and shopping activities are still the most popular. Eating and drinking activities, which were significant for city centre cases, almost disappear in the edge areas.
Survey shows that for all areas, participants living there are mostly students (Figure 5). Additionally, most of the activities are dominated by students in all areas, especially those related to commercial purposes such as shopping, eating, and going to pubs or cafes. However, results for the city centre area in Nottingham were not significantly similar. On the other hand, in the other type of campus areas some of the commercial activities disappeared. For example, in Nottingham it was eating and for Eskisehir it was the cinema and going to pubs and bars, or activities related to domestic life or worship.
Figure 5 - Illustrations reveal the activity of selected area users according to survey results (above). Charts show the distribution of activities in areas and user types according to survey (below).
4.1 CITY CAMPUS AREAS

The purpose of the tracing exercise was to view the distribution of users’ movement in the survey areas and evaluate students’ and non-students’ movement patterns. According to Hillier et al. (2012), analysis at radius 400 or 800 are useful for indicating the spatial structure of local high streets, which have various kinds of activity. An intermediate scale between local and global scale is radius 1000, and higher scales such as radius 2000 and 3000 reveal global road networks. The reason for choosing these values is to interpret tracing results in relation to the syntactic radius to indicate the nature of the local movement pattern in relation to a range of urban scales.

In Nottingham, area selection was more complicated for this type of campus than in Eskisehir. The primary reason was that student household distribution was concentrated in two areas, with more than 40% (Figure 6). Therefore, the survey was conducted in two different areas: the north of the NTU around Mansfield Road and the south around Upper Parliament Street.

The survey results show that student and non-student user percentages are very close but in both areas non-students are over 50%. Therefore, there is not significant student domination in this centre campus, but the surrounding areas are interface areas since more than 50% of participants who live there are students. In addition, 25% of participants work in the area so there are many office buildings.

Mansfield Road and Upper Parliament Street are the two streets with the highest value in choice analyses (Figure 6). Tracing results demonstrate that non-student participants’ routes cover a wider area than students’ and these roads are the higher-value ones in choice r2000 analysis. According to Mansfield Road tracings specifically, students stayed in the triangle between Mansfield Road and the parallel road, Sherwood St, or streets that intersect them. Movements were similar in nearby Upper Parliament Street. Students’ routes overlap highly with non-students’; however, non-students’ have a wider range of starting and end points. This shows that this area is attractive for both user types as daily usage, but for students the area is attractive for living because of its proximity to the university.

In Eskisehir, the movement tracing area was selected according to the distribution of student accommodation and university location. It is notable that background area, which is around University Street, is the place in which many studio flats sprung up after 2000 to fill the empty spaces in the urban grid (Figure 7). In this area, the tracing results indicate that 75% of users are students and their routes are more distributed along the background network than non-students’. Non-student users mostly choose streets that have high value in choice analysis and 40% of non-student participants are in the area because of the university, while 50% are only passing through.
Figure 6 - Illustration of tracing and questionnaire results and normalised choice analyses for city centre campus area of Nottingham.
Hillier’s (1996) theory of movement economy suggests that development of the spatial organisation of settlements depends on areas of busier and quieter movement pattern flows, and that these patterns affect land use decisions. Identification of these changes and movement patterns influences future land use choices and local grids to adapt improvements that are more intensive. The influence of movement on land use and production of space will be evaluated and to do this, Eskisehir is a useful example based on improvements over the last decade.

The buildings along Universite Street start from Eskisehir city centre campus and host diverse ground floor use such as restaurants, cafes, grocery shops, local markets, retail, and service facilities (Figure 8). This diversity has rapidly increased over the last decade and the changes are continuing with other streets that have a good integration between them. On the other hand, other research areas do not include these kinds of diversity or rapid changes. In Nottingham city centre campus there have been some changes but they are not along one specific street or related to an area directly.
After 2000, the number of private accommodations significantly increased in Universite Street and unused lands started to fill rapidly in the surrounding areas. The other high street, called Ismet Inonu, started to change in the subsequent years. Old factories and workshops were closed and most of them moved outside of the city. New buildings were erected and existing ones were renovated and transformed, some into entertainment and youth centres, but mostly restaurants, pubs, and bars (Figure 8). On the contrary, ground floor usage is more diverse in Universite Street than Ismet Inonu but both of them have significant changes.

Hillier et al. (2012) propose that, all things being equal, urban shopping streets are maximised in local normalised choice value and some specific values refer some situations such as less than 1.2 shops do not start being a group, 1.3 refers continues shops, 1.4 means a local centre and 1.5 is associated with main centre. University Street which is ending with campus, has a good nature to continues shops in average value, and also even the maximum values in radius 1000 and 2000 are refer to local centers (Table 3). The other street’s values are lower than and in local scale values less than 1.2, but between local and global scale, values are suitable for grouping shops. So, both streets have significant attractiveness in intermediate scale.

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<th>Normalised angular analysis</th>
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<td>Average</td>
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<td><strong>Ismet Inonu Street</strong></td>
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<td>Min.</td>
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<td>Max.</td>
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Table 3 - Universite and Ismet Inonu Street’s normalised angular choice analysis results.

Figure 8 - Map illustrates the present land-use map of Eskisehir city centre. (Based on map provided from municipality and land-use information was input by author) and aerial pictures highlight the transformed area in last decade. (Base map source: Google Earth)
4.2 THE EDGE CAMPUS AREAS

Osmangazi area is in the eastern part of the campus and the accommodation facilities detected only in this area for OGU and also student’s questionnaire notes demonstrates that most of them live in studio flats or shared apartments which are located this area. The unoccupied land changes between 2002 and 2015 were mostly residential low-height apartments, with the ground floors are used for residential purposes (Figure 9). However, syntactic analyse in radius 2000 which is representing intermediate scale show that the streets of the area have a high value. The participants are mostly students here (80%). The tracing paths demonstrate that non-students are also using the background network since 50% of non-students live there. Besides, some of the destination line of student traces end or start at Tepebasi, which is the Anadolu University area. It means that some students prefer to walk between city centre campus and this area.

According to the results for Nottingham (Figure 10), 76% of participants are students here and this area has the highest rate of student households in all Nottingham. Specifically, in the area between Derby and Ilkeston Roads, which are roads with a high value in radius 1000 and 2000, approximately 65% of households accommodate students. At a local scale, the area is a totally residential part of the city and there is not a significant local centre, but a normalised choice radius 2000 map demonstrates that this area is mid-range, between local and global. The movement pattern of students is mainly on Derby Road. This area does not include any local retail activity except the only shop, a chain market, and also there is a cinema and bank.
Figure 10 - Illustration of tracing results and normalised choice analyses for edge of the city campus area of Nottingham.
5. DISCUSSION

The survey data and analysis show that the area of city centre campuses which have the first higher educational buildings in each town, have diversity in economy and user activity. In addition to this, non-student users mostly use only high streets in those areas. However, students’ movement also has variety and distribution through residential areas. Moreover, in both city centre areas, building transformation has occurred – in Eskisehir’s case small workshops and old factories have been turned into entertainment centres. Vaughan et al. (2010) suggest that for suburban town centres, the potential embedded in the street network is the key element of providing vitality in local centres and also the activities of someone such as routine, extensive and varied ones become a reason of movement in specific area. In this case, it might be said that going to university as a daily routine activity of students therefore, the AU campus might be the reason for enhancing the potential routine movements in neighbourhood area and provide regular usage of this area by students and academic ‘guilds’. This routine movement pattern facilitated the transformation of the area from industrial site to entertainment streets according to their segment’s potential in whole structure.

Nottingham city centre campus area that includes Mansfield Road and Upper Parliament Street, appears to be an interfacing area between students and non-students. It is not dominated directly by students, but in local scale analysis, students become a characteristic of the area. It is notable that this area is more complicated than Eskisehir. This complexity might depend on the highest value of the area in syntactic analysis and also the historical background, since this study does not cover the changes before and after first university settlement. Only some small changes have been detected in recent years. It is clear that this area is one of the preferable living places for students, but the reason for the changes is the presence of students or presence of students’ reason is these changes is not clear. Thus, this may be a controversial and complex topic than it seems and it may be evaluated further with detailed research by analysing land use changes since the university open in there.

Syntactic analysis shows that edge campuses are located in accessible locations in towns, not only for students but also for all users, although they are gated and have own internal structure. This might affect the urban pattern and the development of some surrounding areas. The student areas were framed by high value streets in intermediate scale in both cases. This also might be the reason for these cities’ reputations as student towns since in city centre; student pattern is highly tangible because of their location’s centrality.

6. CONCLUSION

This study aims to explore the university and town relation and university campus influence on the sustainability of a town as a creative city. The urban structure of the two cities were analysed to understand more about how their spatial morphology relates to their current socio-economic situation in the context of presence of students. There is a pretty simplistic idea of the role of universities in the development of cities, and these have been invoked as part of a push to make ‘creative cities’ attractive to urban decision makers. The study suggests that the university-town relationship and its dual benefits is a complex urban phenomenon. However, students provide vitality, and the study suggests that the differences between student and non-student users’ movement patterns affects the production of space and enhance usages of different areas. Overall students are settled down more in relatively integrated areas of the city and participate in the movement economies of these areas. A spatial-morphological analysis suggests how universities, students and student life in cities cannot be artificially separated from the life of the city as the popular image of ‘town and gown’ might suggest – on the contrary, the historic relationship of the city and the university continues to create new synergies - and challenges – that need to be the subject of research.
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THE ECONOMIC VALUE OF SPATIAL NETWORK ACCESSIBILITY FOR UK CITIES: 
A comparative analysis using the hedonic price approach

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ABSTRACT
Spatial network accessibility was found to be significant when associating with house prices using the hedonic price approach. These results suggest some individuals are willing to pay more for spatial isolation while some individuals will pay more for spatial co-presence. An obvious limitation of earlier research is a lack of comparative analysis between cities. Focusing on a single case study reduces the generalisability of the results and the extent to which different spatial contexts might value accessibility differently. The aim of this research was therefore to study the extent to which spatial network accessibility effects differ across cities in the UK. A hedonic price approach was used to explore the extent to which these differences are related to social-economic-mobility factors. Results show, both visually and quantitatively, the economic value of accessibility, measured using space syntax analysis, differs across geographical regions. The accessibility effect on house price ranges from strongly significant in London to insignificant in Birmingham. In general, the economic effect is weaker in smaller, more car dependent cities, with a greater proportion of the population employed in the manufacturing sector, and is stronger in cities that are denser, more walkable with greater productivity and a greater proportion of residents in the education sector. This exploration therefore suggests that the economic value placed upon urban accessibility may be related to a combination of mobility factors, its urban form and its economic profile. Finally, it appears that city productivity as measured by GVA is correlated with increased value placed upon accessibility.

KEYWORDS
Spatial networks, accessibility, hedonic price model, UK, space syntax
1. INTRODUCTION

The economic value of accessibility is an important topic in urban research. As Webster (2011) noted, if accessibility had an economic value, it could then be allocated more efficiently, costs of infrastructure could be recovered and urban designers would be able to weigh objectively between alternative designs. Webster (2011) suggests one approach in retrieving the economic value of accessibility is through the hedonic price approach. (Rosen, 1974). Applying the hedonic price approach, both spatial network accessibility (Law et al., 2013; Xiao, 2015) and land use accessibility (Shen and Karimi, 2016) were found to be significant factors associated with house prices. More simply, some individuals are willing to pay more for accessibility and some less. An obvious limitation from previous research is the focus on single case study cities. Focusing on a single case study reduces the generalisability of the results and the extent to which different spatial contexts might value accessibility differently. Do individuals in different cities value accessibility differently and importantly why might they differ? Could these differences relate to social-economic factors, mobility factors or possibly urban form factors? The aim of this research was therefore firstly to study the extent to which spatial network accessibility effects differ across cities in the UK, and secondly to explore the extent to which these differences relate to a cities’ socio-economic-mobility factors. The results improve our understanding of the effects of spatial network accessibility on house price. The study employs the hedonic price approach in estimating the effects of spatial network accessibility on house price using the sold house price dataset for twenty-three cities in England.

The remainder of the paper is organised as follows: Section One introduces previous research into effects of accessibility on house prices; Section Two introduces the specification for calculating spatial network accessibility using a space syntax approach; Section Three provides details for the empirical method; Section Four introduces the case study and the dataset; Section Five reports the empirical results, Section Six discusses some of the results, drawing conclusions and reviewing the limitations of the research.

1.1 PREVIOUS LITERATURE

Following Rosen’s economic framework (1974) and Ridker and Henning’s empirical study (1967), the hedonic price method has become one of the most popular approaches to the valuation of intangible goods such as school quality or pollution (Black 1999; Ridker and Henning, 1967), and as inputs in land use and transportation models (Waddell, 2002; Lochl and Axhausen, 2010). The theory undermining the use of accessibility came from the concept of spatial equilibrium and its exposition through a monocentric model. Spatial equilibrium or spatial tradeoff theory originated from Von Thunen’s study on the location of market places. He found agricultural activities that were most sensitive to transport costs and consuming the least land were located near the market (Von Thunen, 1826). Following this seminal work, Alonso (1964) Muth (1969) and Mills (1972) developed a related urban monocentric model to explain the centralisation of business and commercial activities where density, land rent and house price diminishes away from the centre. The model operated through a bidding process whereby the people who capitalise the most from the assets acquire the right to the land in a property market. The essence of the monocentric model is its simplicity in explaining land rent through transport cost to determine the location of residents relative to its workplaces.

Based on the monocentric model, location differential is traditionally estimated in the form of “Euclidean Distance to the Central Business District (CBD)” in hedonic price modelling (Kain and Quigley, 1970). One limitation is that this require the endogenous definition of a CBD location and that inner city decline coupled with rising suburban employment led to the diminishing influence of central places. For example, Heikila et al (1989) found that house prices rise rather than fall with distance from the CBD in the Los Angeles Metropolitan Area. This led to the use of multiple employment accessibility models. The motivation of these approaches is that it moves away from the idea of all economic activity concentrated in a single dimensionless point to a more heterogenous distribution of employment.
A second limitation is that these geographic measures of accessibility focused less on general accessibility effects as explained by Webster (2010). This has led to interest in research from the field of space syntax which has methods to allow the quantification and valuation of general accessibility. Empirical research found significant positive associations between spatial network accessibility and council tax band in London (Chiaradia, Hillier, Barnes, Schwander, 2012a; 2012b), house price in Cardiff (Xiao et al. 2015; Narvæel et al. 2014; Narvaez 2015), house price in Shanghai (Yao and Karimi 2015) and house price in London (Law et al. 2013). Despite the identification of associations between spatial network accessibility and house price, studies to date have focused on a single case rather than drawing on multiple cases across different cities.

Recent research suggests that the influence of accessibility can differ both geographically and across time. For example, McMillen (2003) found strong evidence in Chicago CBD where the effect of employment accessibility on house price was significant before 1980, insignificant in 1980 but significant again in 1990. This might be explained by the inversion in the social geography of residential location which appears to be taking place in a number of cities around the world (Ehrenfelt 2012). Under similar vein, Hennerberry (1997) found in the UK the effects of the new tramway in Sheffield had a stronger effect before construction than under operation. This shows the effect of a transport infrastructure project may be complex and can be capitalised during different stages of the development. The key objective of the study presented here is to test the extent to which spatial network accessibility effects exist across different cities in the UK for 2001 and 2011 house price datasets. The next section will begin by setting out the specification for the space syntax definition of spatial network accessibility and the empirical method.

2. METHOD

2.1 SPATIAL NETWORK ACCESSIBILITY

In Walter Hansen’s seminal paper “How accessibility shapes land use” (Hansen, 1949), accessibility was defined as a measure of potential interactions, or relative proximity or nearness in an environment for individuals or places to all others. This study will employ the space syntax measure of integration (Hillier and Hanson, 1984; Hillier et al., 2012) also known as closeness centrality in the network science literature. For a weighted dual graph G=(V,E) where vЄV are the streets and eЄE are the junctions, Integration or Closeness C at metric radius r measures the reciprocal of the average (angular) distance between every origin i to every destination j on least angular deviation paths. More simply, the index measures the to-movement potential of a space in the system (Freeman, 1977). Empirically, closeness centrality had been found to associate positively to residential property values and commercial rent. More formally:

\[ C_i(r) = \frac{N_i(r) - 1}{\sum_{d_{ij}(r)}} \]  

Where \(C_i\) denotes the closeness centrality and \(N_i\) denotes the node count and \(d_{ij}\) denotes the angular distance between every space at radius r.

2.2 EMPIRICAL METHOD

In order to test to what extent a spatial network accessibility effect exists across different cities, this research adopts a three stage empirical process. We begin first by employing a pooled hedonic price model to establish the relationship between house price and accessibility. In the second stage we employ the same hedonic price model for individual case study cities in 2011 and 2001. This will study the extent to which any accessibility effect holds across different cities in the UK. We apply clustering analysis to identify natural clusters of cities in the UK. The third stage then examines how the economic value of spatial network accessibility could possibly be related to different social, economic and mobility factors.
2.3 HEDONIC PRICE MODEL

Rosen (1974) described the hedonic price approach, where a differentiated product such as housing is made up of “utility-bearing” characteristics including structural characteristics, neighbourhood amenity and location accessibility (Cheshire and Sheppard, 1995; Sheppard, 1999). We will adopt this method in two ways; a pooled hedonic price model and an individual-city hedonic price model.

2.4 POOLED-CITY HEDONIC PRICE MODEL

The pooled-city hedonic price model studies the effect of accessibility using a pooled-city least square dummy variable regression specification (LSDV). The standard cross section LSDV model is described in the following equation. This is estimated first for 2001 and then for 2011 datasets.

\[
\log P_{ij} = \theta X_{ij} + \beta A_{ij} + \alpha D_j + e_{ij}
\]  

Where \( P \) denotes the price of a property at the postcode level \( i \), \( X \) represents a vector of independent controlled variables, \( A \) denotes the closeness centrality variable in the model, \( D \) is a city-specific dummy variable for each city \( j \) and \( e \) is the error term. The first order condition of this function is the implicit price or the economic value for the accessibility variable. This allows the property price to be decomposed into its constituents, which can be valued separately.

2.5 INDIVIDUAL-CITY HEDONIC PRICE MODEL

Instead of analysing the pooled effect of accessibility, the individual-city subset hedonic price regression model will study the effect of accessibility for each city separately. For each city, one regression would be estimated for 2001 and one would be estimated for 2011. Equation (03) shows the standard OLS regression model which is similar to the pooled regression model without the city-specific dummy variable. The beta estimates in this case the implicit price of accessibility for individual cities. There are obvious limitations concerning omitted variable bias such as the exclusion of neighbourhood amenity variables which will be discussed at the end of the paper.

\[
\log P_i = \mu X_i + \beta A_i + e_i
\]  

Where \( P \) denotes the price of a property at the postcode level, \( X \) represents a vector of independent controlled variables, \( A \) denotes the closeness centrality variable in the model, and \( e \) is the error term.

2.6 CLUSTERING ANALYSIS

To further understand the differences between individual cities’ economic value of accessibility we will explore the data to see if natural clusters exists in the data. This study will adopt one of the standard techniques, the K-means clustering technique (MacQueen 1967) which aims to partition \( n \) observations into the \( k \) clusters that minimise the differences between the implicit price of accessibility for individual cities.

2.7 SOCIO-ECONOMIC-MOBILITY EXPLORATORY ANALYSIS

After calculating the hedonic price model between cities, we will compare the beta estimates in equation (3) for each city, in order to determine the extent to which different cities value accessibility differently. We conjecture in this research that there are significant differences
between cities. To further explore the plausible reason for these differences, we will statistically correlate the beta estimates with different social, economic and mobility factors for each city. The bi-variate correlation takes the following form where the beta for each city $j$ will correlate with its respective social, economic and mobility factors.

$$\log \beta_j = \alpha \log X_j + e_j \quad (4)$$

Where $\beta$ denotes the beta estimates for equation (3), $X$ denotes the vector of social, economic and mobility factors to be tested in the study and $e$ is the error term.

This comparison will explore plausible reasons why certain cities value accessibility more than others in the UK. The key variables include demographic factors such as size, population density and employment density, economic factors such as gross value added (GVA), Gini coefficient (a measure of inequality) and industry proportions and mobility factors such as the transport modal split.

3. CASE STUDY AND DATASETS

3.1 CASE STUDY

This study is framed within the area of England in United Kingdom focusing on its twenty largest cities. In addition, we included Milton Keynes, Oxford and Cambridge as special cases. This study uses the primary urban area from the ODPM (2006) as study area boundary for analysing

Figure 1 - Case study cities.
the largest English cities. Figure 1 shows the study area and the case study cities.

3.2 DATASET

In order to investigate the relation between spatial configuration and house price, three datasets have been used. This includes the house price dataset, the street network dataset and the census dataset.

3.3 HOUSE PRICE DATASET

The first data set is the sold house price dataset in the UK. It contains for each sold property its attributes such as size, dwelling type, age and tenure. The source of the data is Land Registry and Nationwide Building Society. There are a total of 17,552 transactions in 2011 and 24,988 transactions in 2001 for the twenty-three cities. Table 3 shows the list of the variables included in the hedonic price model. This research has used a parsimonious set of variables which is a limitation to the study. The exclusion of neighbourhood amenity variables is an obvious limitation.

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space Syntax Integration</td>
<td>Location Variables</td>
<td>Continuous</td>
</tr>
<tr>
<td>Dwelling type</td>
<td>Structural Variables</td>
<td>categorical</td>
</tr>
<tr>
<td>Dwelling size</td>
<td>Structural Variables</td>
<td>Continuous</td>
</tr>
<tr>
<td>Age of building</td>
<td>Structural Variables</td>
<td>Ordinal</td>
</tr>
<tr>
<td>Tenure</td>
<td>Structural Variables</td>
<td>categorical</td>
</tr>
<tr>
<td>Number of bedrooms</td>
<td>Structural Variables</td>
<td>number</td>
</tr>
<tr>
<td>Case Study Cities</td>
<td>City-specific Variable</td>
<td>categorical</td>
</tr>
</tbody>
</table>

Table 1 - Hedonic model variables specification

Figure 2 describes house price in the UK for both 2001 and 2011 where the black line denotes the case study cities.

![Figure 2 - UK House price GIS maps. a. 2001 sold price | b. 2011 sold price](image)

1 Primary Urban Areas are defined as continuous built-up areas which have a minimum size cut-off of 125,000 inhabitants in the UK. (ODPM 2006)

2 The nationwide dataset is a subset of the Open Source Land Registry dataset through a licensing agreement with London School of Economics. The origins of all data on sold house prices in United Kingdom is owned by Land Registry/Registers of Scotland © Crown copyright 2013.
3.4 STREET NETWORK DATASET
The second dataset is the spatial model of UK derived from the Ordnance Survey Meridian 2 data set in 2011 (see figure 3a). There are a total of 2,033,012 street segments in the mainland UK. Figure 3b. shows the integration values at radius 50km of the meridian line network and Figure 3c. shows a multi-scale representation of the UK integration maps. Northern Ireland has been excluded as it does not have a physical connection to mainland UK.

Figure 3- a. UK meridian line street network. | b. UK Integration at radius 20km. | c. UK Integration maps for different radii. Diagram produced in Law and Versluis (2015).

3.5 CITIES DATASET
The third dataset is the cities dataset that came primarily from two sources, namely the census dataset produced by the Office of National Statistics (ONS) and the Centre for Cities dataset (Centre for Cities, 2016). Table 02 describes statistically these various datasets at the city level. This includes size, population, employment, travel to work mode and employment statistics. This dataset will mainly be used for the city comparison analysis.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Description</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>area</td>
<td>city area</td>
<td>48,303</td>
<td>59,483</td>
<td>4,069</td>
<td>302,988</td>
</tr>
<tr>
<td>pop</td>
<td>population</td>
<td>925,696</td>
<td>1,698,462</td>
<td>108,863</td>
<td>8,389,587</td>
</tr>
<tr>
<td>emp</td>
<td>employment</td>
<td>423,817</td>
<td>789,998</td>
<td>49,251</td>
<td>3,921,586</td>
</tr>
<tr>
<td>Pop_den</td>
<td>population density</td>
<td>17.9</td>
<td>7.5</td>
<td>6.7</td>
<td>29.4</td>
</tr>
<tr>
<td>Emp_den</td>
<td>employment density</td>
<td>8</td>
<td>3.4</td>
<td>3.4</td>
<td>13.2</td>
</tr>
<tr>
<td>age_0_19</td>
<td>population age 0-19</td>
<td>25.3</td>
<td>1.9</td>
<td>21.6</td>
<td>29</td>
</tr>
<tr>
<td>age_30_44</td>
<td>population age 30-44</td>
<td>22.3</td>
<td>1.2</td>
<td>20.2</td>
<td>25.4</td>
</tr>
<tr>
<td>age_45_64</td>
<td>population age 45-64</td>
<td>22.3</td>
<td>1.6</td>
<td>17.8</td>
<td>24.6</td>
</tr>
<tr>
<td>age_65_</td>
<td>population age 65+</td>
<td>15.1</td>
<td>2.3</td>
<td>10.3</td>
<td>22.5</td>
</tr>
</tbody>
</table>
## Table 2 - Descriptive statistics for ONS population, travel-to-work and employment dataset

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Description</th>
<th>Mean</th>
<th>St. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
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<td>Gini_13</td>
<td>Gini coefficient 2013³</td>
<td>0.4</td>
<td>0.02</td>
<td>0.4</td>
<td>0.5</td>
</tr>
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<td>GVA_pw11</td>
<td>GVA per worker 2011¹</td>
<td>48,006</td>
<td>8,004</td>
<td>40,923</td>
<td>69,227</td>
</tr>
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<td>Ind_per</td>
<td>manufacturing jobs percentage</td>
<td>8.2</td>
<td>3.6</td>
<td>2.6</td>
<td>17.2</td>
</tr>
<tr>
<td>Fin_per</td>
<td>finance jobs percentage</td>
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<td>0.01</td>
<td>0.01</td>
<td>0.1</td>
</tr>
<tr>
<td>Edu_per</td>
<td>education jobs percentage</td>
<td>0.1</td>
<td>0.02</td>
<td>0.04</td>
<td>0.1</td>
</tr>
<tr>
<td>walk_per</td>
<td>walk percentage</td>
<td>10.7</td>
<td>2</td>
<td>6.9</td>
<td>15.5</td>
</tr>
<tr>
<td>PT_per</td>
<td>public transport percentage</td>
<td>14.8</td>
<td>7</td>
<td>6.4</td>
<td>38.5</td>
</tr>
<tr>
<td>car_per</td>
<td>private car percentage</td>
<td>62</td>
<td>9</td>
<td>41.8</td>
<td>72.7</td>
</tr>
<tr>
<td>non_car_per</td>
<td>non-private car percentage</td>
<td>30.1</td>
<td>8.9</td>
<td>18.7</td>
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</tr>
<tr>
<td>area</td>
<td>city area</td>
<td>48,209</td>
<td>59,325</td>
<td>4,068</td>
<td>302,052</td>
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<tr>
<td>pop</td>
<td>population</td>
<td>1,015,765</td>
<td>1,918,236</td>
<td>123,867</td>
<td>9,480,417</td>
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<tr>
<td>emp</td>
<td>employment</td>
<td>476,259</td>
<td>938,059</td>
<td>59,437</td>
<td>4,656,358</td>
</tr>
<tr>
<td>Pop_den</td>
<td>population density</td>
<td>19.5</td>
<td>8.4</td>
<td>7.7</td>
<td>33.3</td>
</tr>
<tr>
<td>Emp_den</td>
<td>employment density</td>
<td>9.1</td>
<td>4</td>
<td>3.8</td>
<td>15.4</td>
</tr>
<tr>
<td>age_0_19</td>
<td>population age 0-19</td>
<td>24.4</td>
<td>1.8</td>
<td>20.9</td>
<td>28.8</td>
</tr>
<tr>
<td>age_20_29</td>
<td>population age 20-29</td>
<td>16.3</td>
<td>3.4</td>
<td>12.8</td>
<td>26.1</td>
</tr>
<tr>
<td>age_30_44</td>
<td>population age 30-44</td>
<td>20.8</td>
<td>1.6</td>
<td>18.7</td>
<td>24.9</td>
</tr>
<tr>
<td>age_45_64</td>
<td>population age 45-64</td>
<td>23.7</td>
<td>2.1</td>
<td>18.2</td>
<td>26.6</td>
</tr>
<tr>
<td>age_65+</td>
<td>population age 65+</td>
<td>14.7</td>
<td>2.3</td>
<td>11</td>
<td>21.7</td>
</tr>
<tr>
<td>Gini_13</td>
<td>Gini coefficient 2013</td>
<td>0.4</td>
<td>0.02</td>
<td>0.4</td>
<td>0.5</td>
</tr>
<tr>
<td>GVA_pw11</td>
<td>GVA per worker 2011</td>
<td>48,006</td>
<td>8,004</td>
<td>40,923</td>
<td>69,227</td>
</tr>
<tr>
<td>Ind_per</td>
<td>manufacturing jobs percentage</td>
<td>8.2</td>
<td>3.6</td>
<td>2.6</td>
<td>17.2</td>
</tr>
<tr>
<td>Fin_per</td>
<td>finance jobs percentage</td>
<td>0.04</td>
<td>0.02</td>
<td>0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>Edu_per</td>
<td>education jobs percentage</td>
<td>0.1</td>
<td>0.02</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>walk_per</td>
<td>walk percentage</td>
<td>11.1</td>
<td>2.6</td>
<td>7.1</td>
<td>17.5</td>
</tr>
<tr>
<td>PT_per</td>
<td>public transport percentage</td>
<td>14.9</td>
<td>8.1</td>
<td>7.4</td>
<td>44.6</td>
</tr>
<tr>
<td>car_per</td>
<td>private car percentage</td>
<td>60.1</td>
<td>11.8</td>
<td>33.5</td>
<td>74.3</td>
</tr>
<tr>
<td>non_car_per</td>
<td>non-private car percentage</td>
<td>31.2</td>
<td>11.1</td>
<td>18.5</td>
<td>56.8</td>
</tr>
</tbody>
</table>

³ We do not have the GINI coefficient data at the city level for 2001 and 2011. We have thus used the 2013 data for both regression model.

⁴ We do not have the Gross value added data (GVA) at the city level for 2001. We have thus used the 2011 data for both regression model.
The figures below describe visually the population and employment density mapped in GIS from light red to red and workplace density mapped in GIS from light blue to blue for each local authority in the UK. Population and employment density scales linearly to spatial network accessibility which suggest spatial network centrality can act as a proxy for employment accessibility in the UK context.

Figure 4 - a. Population density in the UK. | b. Workplace density in the UK.

4. RESULTS

This section summarises the empirical results for the three sections namely the pooled-city hedonic price model, the individual-city hedonic price model and the cities comparison analysis.

4.1 POOLED-CITY HEDONIC PRICE MODEL RESULTS

We start by examining the overall relations between accessibility and house price for the twenty-three case study cities in a pooled-regression model. The hedonic price model is estimated as a pooled-city least square dummy variable regression model (LSDV). Figure 1 illustrates on the left spatial network integration at 20km radius (R20k) and on the right house price per sqm. Visually, there are obvious similarities between city-scale space syntax integration and house price per sqm. This is logical as spaces with greater centrality have greater numbers of jobs leading to higher wages and hence higher house prices. We note only the transactions within the twenty-three primary urban area boundaries were considered in the model. The reason is that accessibility is likely to exhibit a different effect for small cities and rural areas.
The pooled hedonic price model achieved a significant $R^2$ of 74% for both 2001 and 2011. See Table 03 and Table 04. Space Syntax integration $R_{20k}$ was a significant variable in both time periods and the implicit prices for spatial network accessibility rose from 0.15 in 2001 to 0.21 in 2011. This finding is like previous research (Law et al. 2013), where the value of centrality has been found to be dynamic over time and where there appears to be a resurgence of central places in recent years.

Figure 5 - Integration and House Price.
### Table 3 - Pooled hedonic price model results 2011.

| 2011 model                  | estimates | std error | t ratio | prob>|t |
|-----------------------------|-----------|-----------|---------|------|
| Intercept                   | 9.596     | 0.046     | 209.48  | <.0001|
| Type[Conv Flat]             | 0.057     | 0.019     | 2.95    | 0.0031|
| Type[Conv Maisonette]       | -0.349    | 0.11      | -3.17   | 0.0015|
| Type[Detached]              | 0.193     | 0.019     | 10.38   | <.0001|
| Type[Detached-bungalow]     | 0.264     | 0.022     | 12.19   | <.0001|
| Type[PB Flat]               | -0.066    | 0.019     | -3.55   | 0.0004|
| Type[PB Maisonette]         | -0.194    | 0.072     | -2.68   | 0.0074|
| Type[Semi-bungalow]         | 0.124     | 0.023     | 5.43    | <.0001|
| Type[Semi-detached]         | 0.029     | 0.018     | 1.61    | 0.1083|
| tenure[Freehold]            | -0.016    | 0.006     | -2.54   | 0.112 |
| Bedooms                    | 0.054     | 0.004     | 12.66   | <.0001|
| Floor size                 | 0.007     | 0         | 69.9    | <.0001|
| Age                        | 0.001     | 0         | 9.15    | <.0001|
| Integration R20,000m        | 0.214     | 0.006     | 36.37   | <.0001|
| Case Study[Birmingham]      | -0.252    | 0.008     | -30.07  | <.0001|
| Case Study[Bournemouth]     | 0.246     | 0.013     | 19.19   | <.0001|
| Case Study[Bradford]        | -0.255    | 0.02      | -13.01  | <.0001|
| Case Study[Brighton]        | 0.451     | 0.013     | 33.64   | <.0001|
| Case Study[Bristol]         | 0.137     | 0.01      | 13.33   | <.0001|
| Case Study[Cambridge]       | 0.689     | 0.026     | 26.15   | <.0001|
| Case Study[Huddersfield]    | -0.277    | 0.019     | -14.29  | <.0001|
| Case Study[Leeds]           | -0.174    | 0.013     | -13.19  | <.0001|
| Case Study[Leicester]       | -0.19     | 0.015     | -12.5   | <.0001|
| Case Study[Liverpool]       | -0.403    | 0.016     | -24.63  | <.0001|
| Case Study[London]          | 0.483     | 0.006     | 82.19   | <.0001|
| Case Study[Manchester]      | -0.259    | 0.01      | -25.6   | <.0001|
| Case Study[Middlesbrough]   | -0.244    | 0.018     | -13.27  | <.0001|
| Case Study[Milton Keynes]   | 0.136     | 0.016     | 8.42    | <.0001|
| Case Study[Newcastle]       | -0.332    | 0.012     | -26.64  | <.0001|
| Case Study[Nottingham]      | -0.297    | 0.013     | -22.14  | <.0001|
| Case Study[Oxford]          | 0.689     | 0.026     | 26.58   | <.0001|
| Case Study[Portsmouth]      | 0.167     | 0.012     | 13.95   | <.0001|
| Case Study[Prenton]         | -0.229    | 0.018     | -12.76  | <.0001|
| Case Study[Reading]         | 0.396     | 0.011     | 34.76   | <.0001|
| Case Study[Sheffield]       | -0.25     | 0.014     | -17.79  | <.0001|
| Case Study[Southamption]    | 0.175     | 0.014     | 12.59   | <.0001|

R2                        | 0.74      |           | F-ratio | 1424.35|
R2 Adj                     | 0.739     |           | Prob>F   | <.0001|
RMSE                       | 0.276     |           |         |       |
Observations               | 17552     |           |         |       |
<table>
<thead>
<tr>
<th>2001 model</th>
<th>estimates</th>
<th>std error</th>
<th>t ratio</th>
<th>prob&gt;t</th>
</tr>
</thead>
<tbody>
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<td>Intercept</td>
<td>9.602</td>
<td>0.053</td>
<td>181.87</td>
<td>&lt;.0001</td>
</tr>
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<td>0.034</td>
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<tr>
<td>Type[Conv Maisonette]</td>
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<td>0.262</td>
<td>1.87</td>
<td>0.061</td>
</tr>
<tr>
<td>Type[Detached]</td>
<td>0.082</td>
<td>0.034</td>
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<td>0.016</td>
</tr>
<tr>
<td>Type[Detached-bungalow]</td>
<td>0.216</td>
<td>0.036</td>
<td>6.04</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Type[PB Flat]</td>
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<td>-5.82</td>
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<td>Type[PB Maisonette]</td>
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<td>-3.39</td>
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<td>&lt;.0001</td>
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<td>bedrooms</td>
<td>0.056</td>
<td>0.004</td>
<td>14.63</td>
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</tr>
<tr>
<td>Floor size</td>
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<td>0</td>
<td>73.53</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Age</td>
<td>-0.001</td>
<td>0</td>
<td>-8.83</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Integration R20,000m</td>
<td>0.147</td>
<td>0.006</td>
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<td>&lt;.0001</td>
</tr>
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<td>&lt;.0001</td>
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R2 0.74  F-ratio 2028.226
R2 Adj 0.74  Prob>F <.0001
RMSE 0.294
Observations 24988

Table 4 - Pooled hedonic price model results 2001.
4.2 INDIVIDUAL-CITY HEDONIC PRICE MODEL RESULTS

The second step is to look at the individual-city hedonic price model. Similarly, we zoom in and visualise the results. Figure 6 shows house price per sqm in 2011, on the right, and space syntax integration, on the left, in London, Bristol, Manchester and Birmingham. For both London and Bristol, the results show association between house price and centrality. For both Manchester and Birmingham, the result shows dissociation between house price and centrality.

The regression results show the implicit price for street network accessibility differs significantly across cities. See Table 5. The accessibility effect on house price ranges from 0.6 in London to nearly 0 for Manchester as reflected in the visualisation. Cities such as Bristol, Brighton and Oxford have comparatively higher implicit prices while cities such as Birmingham Leeds, Leicester, Southampton, Preston and Milton Keynes have negative implicit prices for both years. There are cities that have low or negative implicit prices in 2001 but became positive in 2011 such as Liverpool signifying a recentralisation.
The economic value of spatial network accessibility for UK cities: A comparative analysis using the hedonic price approach

<table>
<thead>
<tr>
<th>Beta</th>
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</tr>
<tr>
<td>Cambridge</td>
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</table>

Table 5 - Implicit prices of accessibility for individual cities in the UK.

4.3 CLUSTERING ANALYSIS

To further analyse the implicit price difference between individual cities in the UK, we apply clustering analysis on the economic value of accessibility to see if natural clusters are formed. We employ the k-means clustering algorithm here. Figure 7a is the scree plot which shows the within group sum of squares plotted in the y-axis and the number of clusters in the x-axis. The result shows clearly the most optimal number of natural clusters is 3.
Figure 7b is the cluster plot which shows the scatterplot between the first two principle components of the data. The result shows that there are three natural clusters in the data. It also shows the cluster in the upper-right quadrant can be separated into two sub-clusters. This research will therefore visualise the K=4 solution.

Figure 7c shows the geographical distribution of the four clusters. The red cluster which contains London, Brighton, Cambridge and have generally the highest economic value for accessibility. The yellow cluster which contains Bristol, Reading and Nottingham have lower economic value for accessibility. The green cluster which contains Manchester, Sheffield and Newcastle have near zero value for accessibility. The orange cluster which contains Birmingham, Leeds and Bournemouth have negative economic value for accessibility. These differences can possibly be attributed to a number of socio-economic-physical factors. For example, the cities with the highest economic value of accessibility such as Cambridge and Oxford have generally a higher proportion employed in the education sector, a walkable historic core and an economy strongly tied to London. At the other end of the spectrum, the cities with low and negative economic value of accessibility such as Leeds, Birmingham and Manchester are all located in the north that were heavily dependent on the industrial sector in the past. These results show clear differences between the north and the south and a clear pattern of geographical clustering. The next section will explore these differences against various socio-economic factors.

4.4 SOCIO-ECONOMIC-MOBILITY FACTOR ANALYSIS RESULT

In order to explore the difference between cities, this research examines how a city’s economic value of accessibility co-varies with different social, economic and mobility characteristics. Figure 08 illustrates the scatterplot between the beta estimates on the Y-axis and each population variable on the X-axis. The result shows there is generally a poor relationship between a city’s economic value of accessibility and its size, its population and its employment. However there appears to be a significant positive relationship between a city’s economic value of accessibility to its population and employment density and demographics. The result shows a denser city appears to give a greater economic value to accessibility than a sparser city. The result also shows a city with greater proportion aged between 20-29 appears to give a greater economic value to accessibility than a city with greater proportion aged below 20 or above 45.
Figure 8 - Scatterplot between Beta estimates on the Y-axis and Population variables on the X-axis.

Looking to mobility factors, figure 9 illustrates the scatterplot between the beta estimates on the Y-axis for each mobility variable on the X-axis. The result shows that there is a stronger relationship between a city’s economic value of accessibility and different mobility factors. In this case a more car dependent city has lower economic value of accessibility and vice versa, a more walkable city has higher economic value of accessibility.
Lastly, figure 10 illustrates the scatterplots between the beta estimates on the Y-axis and economic variables on the X-axis. The result shows there is generally a consistent relationship between a city’s economic factor and a city’s economic value of accessibility. For example, a city’s inequality (gini coefficient) and productivity (GVA) correlates positively with higher economic value of accessibility. A consistent relationship was also found between the city’s key sector of employment and the economic value of accessibility. For example, a greater proportion of the jobs employed in the education sector correlates positively with higher economic value of accessibility. Conversely, a greater proportion of the jobs employed in the manufacturing sector correlates negatively with higher economic value of accessibility. However, there is an inconsistent relationship between a city’s proportion of jobs employed in the financial sector relative to its economic value of accessibility. In 2001 there was a negative association between a city’s proportion of jobs employed in the financial sector relative to its economic value of accessibility. This association was reversed in 2011. Further research is needed to explore in more detail and to further disaggregate employment data to gain a better sense of the relationship between the economic value of accessibility and the economic performance of cities.
Table 06 summarises the goodness of fit and significance between a city’s economic value of accessibility and each of the social, economic and mobility variables explored for 2011, 2001 and combined. For brevity, the full regression results are not fully reported. In general, the mobility patterns were most strongly related to a city’s economic value of accessibility followed by the proportion of jobs employed in the manufacturing sector, demographics and the gini coefficient. Put simply, the result suggests that a denser, more productive and less car dependent city with greater proportion employed in the education sector and greater proportion aged between 20-29 is likely to value accessibility more.

Figure 10 - Scatterplot between Beta estimates on the Y-axis and Economic variables on the X-axis.
5. DISCUSSION

Extending from previous research, this research has shown firstly that spatial network accessibility is a significant variable when associating with house price using the pooled-city regression model. The overall implicit price of accessibility for the 23 case study cities in England increased from 0.14 in 2001 to 0.21 in 2011 which confirms the overall recentralisation trend for cities in the UK (Ehrenhalt 2012). The result from the individual-city regression model shown that spatial network accessibility is a significant variable for some of the cities, but not all. It shows the complexity of the housing market where different households under different local conditions and economic structures might value differing levels of accessibility. This supports the general consensus that housing research needs to be conducted under different contexts and at different points in time. Clustering analysis shows cities in the south and especially near London placed higher economic value on accessibility as compared to the cities in the north. These results suggest housing location preferences have a clear geographical clustering, in this case between the north and the south.

Furthermore, the cities where accessibility was significantly positively valued appeared to be denser, more walkable, with greater productivity and greater proportions employed in the education sector and greater proportions aged between 20-29. Conversely, the cities where accessibility was insignificant appeared to be less dense, more car dependent, with lower productivity and with greater proportions employed in the manufacturing sector and greater proportions aged below 20 or above 45 [age<20, age>45]. These results can be interpreted from

Table 6 - Correlation coefficient
a number of points of view. On the one hand, cities that are smaller and more car dependent might be less affected by distance and so households would value accessibility less. On the other hand, larger cities with greater productivity that are less reliant on manufacturing industry could diversify into sectors such as the creative, technological and education sectors that benefit from greater agglomeration and so households might give greater value to accessibility. This could also be related to demographics. A population that has children might be expected to value accessibility to schools more, and a population that are seeking employment opportunities might value accessibility to social networks and jobs more.

However, these effects are complex and conditional. Even for cities that were significant, the effects seem to be greater for larger cities such as London than smaller cities such as Cambridge and Oxford. While cities such as Milton Keynes with great proportions employed in the business sector gave a lower economic value to accessibility. This might be attributed to its urban form which is highly car-dependent and unwalkable. This research therefore suggests that the economic value of residential accessibility is related to a combination of a city’s mobility factors, its urban form and its economic profile. This clearly requires further research and a more detailed analysis of individual cases to elucidate the exact mechanisms at play, however it is clear that the single monocentric model, and its underpinning assumption of a spatial equilibrium is subject to further research.

There are a number of limitations to the current research. Firstly, this research selected a pre-existing primary urban area (PUA) boundary which is based on a resident threshold. The problem of this approach is the boundary can exclude areas that are within the functional boundary of the city but it may also include areas that are outside the functional boundary. Figure 11 shows this clearly where the PUA boundary in the black outline does not match either the political boundary of London in blue nor the commuting patterns overlaid on top. One approach would be to test the stability of the hedonic price model by adopting different urban area boundaries. Secondly, this research suffers from obvious omitted variable bias such as access to schools and access to parks, both of which have found to be implicated (Law et al 2013). A check was done in London and found that the exclusion of the neighbourhood amenity variables, such as access to shops, parks and school quality could underestimate the economic value of spatial network accessibility on house price, but the variable was still highly significant. These additional factors need to be included in future research studies. Thirdly, the simplicity of the specification needs to be addressed in future research. For example, the OLS regression specification is likely to suffer from both spatial autocorrelations and omitted variable bias leading to an over-estimation on
the effect of accessibility. Future research requires a more robust empirical design. Finally, the economic value of accessibility might be related to differing demand from different housing submarkets. As a result, future research should consider disaggregating the data further by different submarkets to explore the relationship between the economic value of accessibility and socio-economic-mobility factors.

Finally, this research shows that on average spatial network accessibility is a significant variable when associating with house price variations. However, this relation is more complex than previously thought with some cities showing a significant association and others not. There are clear patterns where some clusters of cities placed greater economic value on accessibility and some clusters placed less. An initial exploration shows cities that value central places more tend to be denser, more productive, had greater proportion employed in the education sector and, most importantly, were less car dependent. This shows urban form factors that influence walkability and density are central to the economic value placed on accessibility, as well as city productivity.
REFERENCES

Ahlfeldt, G. (2010) If Alonso was right: Modeling Accessibility and Explaining the Residential Land Gradient. Journal of Regional Science


#78

CHARACTERIZING URBAN CENTRES

Reading configuration as point, line, field

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ABSTRACT

As cities are growing the need for complementary sub centres increases, both in order to
distribute amenities and to make resources more accessible for citizens, as well as to relieve the
pressure on the city core. Such planning strategy, a kind of decentralized concentration, has
been seen as a mean for holding back urban sprawl in Stockholm. Lately, urban centres are also
argued to contribute to the development of more equal living conditions making opportunities,
service, and urban life accessible also in more peripheral urban locations. The values of ‘suburban
urbanities’ has also been highlighted in a way that reach far beyond the commercial activities
(Vaughan 2015).

The Regional planning authority in Stockholm as well as the City of Stockholm identifies a
number of regional subcentres and ‘urban boulevards’ that should connect the city since and
make it less fragmented. The social incentive for this strategy is prominent in both plans.
However, these subcentres are dependent on urban centrality which needs to be taken into
consideration.

The strength, or the success, of a subcentre is partly influenced by urban design interventions
and is argued to be related to 1) the configurative properties (distribution of space) and 2)
land use parameters and density (distribution in and through space) (Koch 2016; Hillier 1999;
Vaughan 2010). In order to increase the understanding for what urban design interventions that
may be efficient, this paper will draw from the concepts developed by Stan Allen (1999) of point,
line and field and John McMorrough (2001). The combination of the configurative perspective
and the point-line-field perspective is argued to contribute with knowledge of how urban form
generates and supports the emergence of urban centrality and the development of subcentres
with implications not only for consumption and mobility, but also for social outcomes such
as urban life and equal living conditions. The empirical application aims to illustrate how
configurative analysis complement the point-line-field theory in describing the character of
the centres and the findings are argued to contribute to the identification of more precise and
efficient urban design interventions of how to develop the centres.
1. INTRODUCTION

In some neighbourhoods there is only one specific street, or one place, that can be described as ‘central’ and typically, urban life is concentrated here. In other neighbourhoods it could be difficult to identify the most important street, the situation is more diffuse. Urban life is more distributed and non-residential and residential activities are mixed to a higher degree. For a business that depends on influx of customers that would appear only if it is convenient – for instance, drop-in customers – the difference is illustrative; in the first type of neighbourhood there is more or less only one street that offers a possible alternative; a kind of either you are ‘in’ or you are ‘out’ situation. In the other type of neighbourhood the exact location is of less importance. In this paper we will elaborate on how urban centrality is related to the configurative properties and discuss the difference in various urban morphology patterns. We will discuss this as a general phenomenon as many cities today implement strategies with the aim to revitalise and develop new urban centres, and elaborate on how ‘urbanity’ can be encouraged extending and nuancing the question from ‘lively places’ to concepts that incorporate how instances of such urbanity interact with and depend on context. To give concretion we refer to the proposal for new Comprehensive Plan for Stockholm (2016), and the proposal for a new Regional Development Plan for Stockholm (2016). These planning documents emphasise the social importance of subcentres and connecting urban paths, argued to play important roles to decrease segregation, connect a fragmented urban landscape and reach more equal living conditions. These centres are not only business or commercial centres; they should also function as social arenas, facilitating interplay between the citizens and between different social groups. Seen from a configurative perspective the two different situations described above are argued to correspond to different configurative properties. They may be described as two types of urban structures: the hierarchical tree structure and the (deformed) grid structure (Klarqvist 1995; Hillier 1996). These structures are related to different distributions of centrality (see Hillier, 2003) which are influencing aspects like freedom and control. As a result, one may expect different types of use and activities, and they have different implications for social life (Hillier & Hanson 1984; Hanson & Hillier 1987). However, there is a possibility to be more nuanced in the analyses of urban networks; the local properties are influenced by the relatedness of the street network both on the local level in combination with properties on the city level (Peponis 2008; Hillier 2012). The aim is to increase the understanding of how urban form can generate and sustain urban centres as well as embed them in, or distinguish them from their context. The interest lies not only in how centres and paths develop into nodes for communication or nodes for public and commercial service, but also in their social implications such as urban life, walking behaviour, and possibilities to partake of societal resources including commercial, social and other services but also public spaces and other people. The paper uses the discussion of ‘field conditions’ and the concepts of ‘points’ and ‘lines’ drawing from Stan Allen (1999) and John McMorrough (2001). These concepts will be used to read and interpret urban configuration with the aim to capture specific characteristics of centres of relevance for urban life and for what living conditions are created in different parts of the city. We will discuss urban centrality in relation to the goals that the municipality and the region formulate that are about connecting and integrating the city spatially as well as developing new subcentres. The paper concludes that the development of urban centrality is a process related to configuration and that attractions, flows as well as accessibility works within conditions set out by the configurative properties inherent in urban form.
2. URBAN CENTRES – SUBCENTRES

The city and the region of Stockholm is growing rapidly. High urban drift and population increase has resulted in a severe housing shortage (Länsstyrelsen 2016). Planning practice has for long been focused upon expansion and densification simultaneously, and a strategy to meet this expansion has been to develop and create new sub centres in order to distribute service, resources and urbanity as well as bring relief to the inner city that is put under pressure.

In the context of these planning and design processes, urban subcentres can be understood as descriptions of phenomena or as abstractions or symbols for a certain function in a larger context (the city or the region). Most often, an urban centre could be identified as a place of concentrated non-residential activities. During the post-war development in Stockholm typically associated with either high population density, communication network nodes, or concentrations of job opportunities (Granfelt, 1968). It is also in the 20th century the notion of ‘a centre’ as a specific and separate unit becomes dominant, in a similar type of correspondence-thinking as ‘the neighbourhood’ (Hanson & Hillier, 1987). However, the concept of ‘centre’ within architecture and urban design is as Allen (1999) highlights rather different from its more precise definition within physics: it is a kind of double meaning; both in a symbolic sense and in that it should be perceived as a centre in terms of their urban surroundings. In planning documents – comprehensive plans or regional plans – the concepts function as abstract descriptions (compare with ‘abstract space’, Lefebvre 1991). However, as these attributes are to be applied in practice, a more nuanced understanding is necessary for what these nodes in reality are and how urban form in fact can create such urban nodes, centres and paths, an understanding that is closer to how such places function and may be perceived in daily life (compare with Lefebvre’s ‘lived space’). Strategies to develop subcentres are often related to ideas about attractive complements to the city/regional core with the argument to provide citizens outside the urban core with a diversified service supply and to counteract urban sprawl (TMR 2013).

In the Stockholm Comprehensive Plan (2010) nine urban subcentres are identified with related and interconnected urban paths. In the new proposal (2016) the subcentres are less prominent but ideas about connecting the fragmented city and linking different districts/neighbourhoods remains central: The plan proposes a number of urban paths and boulevards. The intention is to create a more connected, walkable city that eases social relations and increases access to urban resources which is believed to result in a more socially sustainable city. Three of the subcentres from the previous plan remain in the new proposal and furthermore includes the whole neighbourhoods where these centres are located. Two of them correspond with the eight regional subcentres in the Regional Plan; Skärholmen and Kista. In the translation to implementation of these proposals we argue that there are tendencies to translate these ‘nodes’ and ‘links’ in the abstract level to ‘points’ and ‘lines’ in the concrete architectural solutions, while the rhetoric rather makes claims better related to ‘fields’.

3. CONNECTING THE CITY – CONNECTING PEOPLE

According to the Comprehensive Plan (2016), one aim is to avoid the development of mono-functional housing areas (suburbia). The strategy aims to counteract segregation and to create more equal living conditions, as residential segregation continues to have a firm hold on the city and the region. There is an increasing socio-economic polarization in spite of political goals advocating increased social integration (Andersson 2013). Segregation is however not limited to residential segregation, in addition there is a spatial separation of social groups as a result of how the citizens use the city in their daily life (e.g. Legeby, 2013); there is a separation in terms of functions as well as in terms of activities (Franzén 2009). To a certain degree this is the result of how our cities are organized spatially, the spatial relations that the built environment creates, both between neighbourhoods and between people (Hanson 2000; Vaughan 2007; Hanson & Zako 2007; Legeby & Marcus 2013; Legeby 2013; Netto el al., 2016). Access to different resources in the city, such as public and commercial service or to social networks, look very different in different parts of the city, which contributes to increased segregation.

1 The region has 2.2 million inhabitants and is expecting 2.6 million by 2030. (Länsstyrelsen 2016).
Figure 1 - Stockholm Comprehensive Plan; 2010 and 2016.
Zukin (1995) argues that those social groups visible in the city and that share public space can participate in the ongoing negotiations about societal norms and attitudes. In a similar line of reasoning, Young (1996) argues that strong separation between social groups may lead to impaired understanding of ‘the other’ and other people’s life conditions as well as reduced trust. In extension, limited exchange between citizens and between different groups in society, has negative effects in general but is especially disadvantageous for groups or individuals with few recourses (Franzen, 2003; Wilkinson & Pickett, 2001). Urban form, through the configurational properties and spatial organization, has a very direct impact on the distribution of resources and the distribution of societal functions. A kind of landscape of collective resources that takes very long time to change (Legeby et al., 2016a; 2016b).

4. URBAN FORM, CENTRALITY AND ‘LOCATION’

The outset for our discussion of the concepts of point, line and field is that the character of individual places are largely defined by their relation to the surrounding spaces, and that this heavily affects social life and affordances, as is set out already by Hillier and Hanson in 1984. For our current investigation, it is not only a question of centrality of individual spaces, but how this relates to local and global context. We draw from how Vaughan et al. (2010) have specifically studied centrality patterns in suburban centres and emphasized the social importance of the high street, and on more abstracted and conceptually, Hillier et al.’s (2012) comprehensive study comparing patterns of urban centrality in different cities, and Marcus’ concept of spatial capital as created through how configuration of urban form interrelates with how property structure is organised (Marcus 2010). We further relate to earlier studies of Stockholm, linking spatial properties to higher inflow of nonlocals and higher urban life-intensity (Legeby 2013; Choi 2015). The underlying principle of this discussion is that an understanding of how urban spaces provides a potential for co-presence is essential in order to reach the goals that are presented in the Comprehensive Plan (2016, 20-23,52) about creating meeting places or social arenas. Urban environments provide possibilities as well as restrictions that influence movement flows and peoples’ appropriation of space. As de Certeau argues:

"...a spatial order organizes an ensemble of possibilities [...] then the walker actualizes some of these possibilities. In that way, he makes them exist as well as emerge." (1984, 98).

In planning documents on the comprehensive level subcentres as well as paths and links are mostly represented in an abstract way. The intent is to not be very precise but to show intentions and illustrate strategies. But when it comes to implementation it is important that we understand what urban design interventions respond to these abstractions. Here, we will discuss how this relates to configurational properties and concepts developed by Stan Allen (1999) and John McMorrough (2001) including ‘point’, ‘line’, and ‘field’. We argue that the understanding of these phenomena can inform and contribute to the understanding of what kind of design interventions may have the ability to support the development of subcentres in Stockholm in a way that also provide them with a potential to be a social arena.

Building on Allen’s work, McMorrough (2001) uses the concepts ‘point’, ‘line’ and ‘field’ in a more concrete way in relation to shopping:

"[...] – where the shop (or boutique) represents the basic unit of shopping, or point; the mall (and its antecedents, the arcade and stoa) represents the linear accumulation of shopping points; and the department store or big box retailing, for example represents the extrusion of the shop/point in all directions into a field, or plane, of consumption.” (2001, 195-198).

This specific understanding can be transferred to a wider range of scales and be applied to a discussion on urban centres. For this purpose, we will go through the concepts more thoroughly in how they are interpreted specifically for our discussion.
4.1 POINT

A point in an urban setting is something that one can move to and from but that only to a limited extent produces movement flows in its proximity. Very few flows pass through the point centre; it tends to be either a destination or an origin. A point can be a single attraction but appear in different scales; one single business, a neighbourhood square or a shopping mall. Urban life may emerge at these kind of places but the tendency is that this only to a limited extent generates movement to the neighbourhood/district where it's located (McMorrough 2001). For example, visitors to the subcentres in Skärholmen and Farsta interact to a limited extent with the district at large. Neither the interface with the surrounding streets nor their configuration encourage different types of activities in the proximity of the centre, rather, only a couple of blocks away land use is mono-functional and dominated by housing. As ‘points’ concentrate urban life to the point itself and are weak in producing urbanity in the neighbourhood as a whole, conditioning co-presence and the possibilities for different social groups to share public space. In such an understanding ‘points’ are created not only by boundaries or functional restrictions, but importantly for our argument, also when configuration creates delimitations between one and the other. McMorrough (2002, 198) argues that urbanity rather decreases as privatization increases for example in shopping environments. Hence, aspects of control and freedom (Markus 1993) are at play as well, where ‘point’ phenomena often provides situations of high control and low degree of freedom.

4.2 LINE

According to McMorrough (2001) lines are paths (or streets) that can be described as an element with a stretched linearity. A line is not a simple connecter between two points; rather lines connect and aggregates points along a certain stretch. Movement flows occur between points but which point that is origin or destination is blurred. Depending on the distribution of the points along such line, flows of different intensity and character emerge. In sequences where route patterns overlap exchange can take place; an active or passive exchange, direct or indirect, as for example by reading a situation from other people’s behaviour (de Certeau, 1984). Goffman (1963) introduces focused and unfocused interaction and Koch et al. (2012) describe primary and secondary benefits that emerge as a result of co-presence and interaction. Lines offer such potentials in how it organises movement and other activities in public space to foster encounters in the process of other activities, such as between one shop and the other, or day-care and home.

4.3 FIELD

When lines that individually are connected with points are aggregating into a cluster Stan Allen (1999) calls this a ‘field condition’. Together, these lines generate flows and possibilities. He argues that a field condition is capable of unifying diverse elements while respecting the identity of each:

“Field conditions are bottom-up phenomena, defined not by overarching geometrical schemas but by intricate local connections. Interval, repetition, and seriality are key concepts. Form matters, but not so much the forms of things as the forms between things.” (1999, 92).

Allen emphasizes the relations between things and translated to urban street structures ‘field conditions’ may appear as a structure that is continuous with gradual shifts of integration, and where interconnectedness reaches large portions of the area. Streets that attract a larger share of movement flows are streets that are used while moving between other lines and points. However, in close proximity from these, more quiet streets appear; providing a kind of back street or alley character. Hence, field conditions create and combine a diversity of different locations within a limited area, something that may be compared to what Marcus refers to as spatial capacity (2010). The location of points (origin/destination) will in fields be blurred and rather be characterized by a continuity of possible destinations/goal points, whereupon according to Allen (1999) focus moves from the individual to the collective, or from object to
field. He emphasizes that fields are created in a bottom-up process and that they are dependent on the configurative relations, in line with how Hillier and Hanson argue (1984, ch.1). One can say that all design components together create a kind of unity of diversity. It is a possibility for a gradual shift of functions and thereby a more nuanced set of options for walking, living and using. Points act quite conversely where the sharp boundaries of points allow for a separation in for example the shopping centre and the housing area.

Additionally, field configurations are inherently expandable (Allen, 1999). This implies that since a field can grow (or shrink) piecemeal it holds affordance for change; it becomes flexible for economic and social shifts (Granfelt, 1968).

The configurative properties that corresponds to ‘field’ are characterized by an aggregation of lines with high integration values however with variations. Such structures provide several equivalent or alternative routes through the area, but are not confined to ‘grids’ or other specific geometrical forms. Field phenomena rarely appear in hierarchal urban structures, which are prevalent in Stockholm’s urban landscape, e.g. areas designed according to the neighbourhood unit model. These areas resist the idea of connecting the city, and creating continuity of the urban fabric will not be solved only by single connectors (e.g. urban path/boulevard). Moreover, in tree structures, the catchment area tends to be limited and the spatial reach narrows down. Often the interface towards neighbouring areas is ruptured (Legeby 2013, Legeby et al. 2015). Such structures provide fewer alternatives for choosing a route, increasing control and predictability (Koch, 2016; Markus, 1993). How people move in these areas is found to correspond to the different configurational properties; in ‘field’ configurations (e.g. SoFo) there is a larger share of so called social walking, while in typical ‘line’ configurations (e.g. Hökarängen) utilitarian walking behaviour is more prominent (Choi 2015).

Figure 2 - Point-line-field-conditions.

5. EMPIRICAL APPLICATIONS

To develop these concepts towards concrete applications, we will analyse configuration and catchment areas, where catchment area is understood as spatial reach and accessible population around the centres. The analyses operate through an axial map, where distances are measured along the axial lines and largely correspond to walking distances in the urban fabric. The selection of analyses showed here include 1) configurative analysis, 2) population density in the catchment area, 3) spatial catchment area (topological reach), and 4) an example of access to amenities.
5.1 CONFIGURATIVE ANALYSIS

The integration analysis describe three scale levels; local (radius 6), a mid-level (radius 16), and a city level (radius 30). By highlighting the most integrated lines at each scale level the pattern that appears illustrates whether integration cores take on point, line or field characteristics. At large, the centrality distributes from the city core in two directions; to the south and to the north-west. The south-sector is highly integrated and largely interconnected, argued to hold a field condition (at r30 and r16) but on a local level fragmentation emerges. The south-west part of the city, where Skårholmen centre is located, is at large weakly integrated to the high integration sector. However, on the mid-scale level, a kind of field pattern emerges in the neighbourhood but without being integrated in its surrounding; meaning that this field in practice acts as a point. Farsta centre is located in the extension of this sector but beyond where centrality reaches. Streets in the neighbourhood features a kind of line characteristics but this linearity acts locally and connections to neighbouring areas are interrupted. Kista centre is outside of high integration core (city level) and weakly connected to the linearity that exists in the district where it’s located. Thus, urban form hinders centrality to distribute both west and north from Kista centre with the result that movement between the centre and the district is not encouraged by the built environment.

The radii chosen are selected since they are found to be relevant in Stockholm for aspects related to co-presence in public space in terms of intensity and the mix of locals and non-locals (Legeby 2013).

Figure 3 - High values: integration radius 6.
Figure 4 - High values: integration radius 16.

Figure 5 - High values: integration radius 30.
5.2 POPULATION IN THE CATCHMENT AREA

How many people live and work around the subcentres reveals the density in their respective area. In some planning traditions such density is what defines a centre; either places that reach a high density of workplaces or a high population density beside aspects of communications (Granfelt, 1968). In this analysis a 3-kilometre distance is used and while Skärholmen and Farsta hold rather similar densities Kista proves to have much higher numbers both in terms of residents and working population.

![Catchment area: population](image)

Figure 6 - Access to population from each centre.

5.3 SPATIAL CATCHMENT AREA

The catchment area of the subcentres is analysed by topological reach since that highlights the properties of urban form (6-10-16-30-step distances). The 6-axial-step-reach shows that Skärholmen expands to the west, but still, it reaches just about the neighbouring centre Vårberg about one kilometre away. In other directions the structure is more fragmented and there is a lack of linearity that reaches out to the surroundings. The catchment area of Farsta has a clear concentric shape and lack linearity that reaches out to the surroundings. It is disconnected to the high centrality stretch that reaches out from the city core. Kista has a catchment area that clearly stretches out towards east, where the business/office area is located but is much weaker to the north where housing dominates. A spatial segregation between working places and housing do not foster interplay, rather, the configurative properties inhibit a mix of local residents and non-locals visiting the mall.

In these three cases it is shown that the interface towards neighbouring areas is ruptured which is clearly obstructive for the development of the subcentre but especially for the neighbourhoods at large. This leaves the subcentres/areas in a segregated position that do not use the latent potential that the closest catchment area could give. Interventions in the urban structure in critical locations could change the situation dramatically so that the context could support the emergence of the subcentre rather than just happen to be located side by side.

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3 Data of the population/workplaces at the address point level and distance measured as walking distance through the street network accessible for pedestrians.
Figure 7 - Spatial catchment area. Skärholmen has a limited catchment area and the spatial relation to Vårberg to the west turns out to be weak. From Kista lines stretch out, stronger to the north than to the south. Farsta centre is rather weakly integrated with surrounding neighbourhoods Hökarängen, Sköndal and Farsta Strand.
5.4 HOW UNEQUAL LIVING CONDITIONS PLAY OUT

Since segregation is closely related to unequal living conditions there is a need to describe how inequalities play out in different urban layouts. Access to resources is dependent on land use (location in space) but also configurational properties (of space) that in a combined analysis reveals distribution through space. Urban centres are strongly related to commercial services but as a way of moving focus from commercial to public service we here present an analysis of streets that connect a selection of public services; namely libraries, facilities for culture schools and community facilities. The map illustrates where continuities as well as fragmentation appears in the urban fabric. This analysis reveals how unequal living conditions play out in the city where some paths and neighbourhoods are characterised by high access and others by absence of amenities. Some areas are much favoured while others more or less lack streets where this service is exposed or accessible. It can also be seen how in some areas the accessibility spreads out into fields, while in others they appear aggregated into lines, and in yet others more or less as points.

![Analysis (attraction betweenness in PST) illustrating the spatial relations between public institutions and amenities (i.e. how many amenities are found within a radius of 280° from each segment; facilities for culture, facilities for assembling, and public libraries.](image_url)
6. CONCLUDING DISUSSION

This paper shows that a point-line-field approach may be combined with and supported by space syntax theory and configurative analysis. A set of different analyses contribute to identify where phenomena of points-lines-fields appear in a city and increases the understanding of how urban form in neighbourhoods may contribute to the emergence of subcentres and to integrate fragmented parts of the city.

We argue, that configurative analyses – revealing whether places hold the characteristics from points, lines or fields – inform practice in where and how to invest in a constructive and bottom-up way. It reveals the possibilities and the restrictions for various uses and social processes that public space offer for its users; hence, affordances are identified. Such understanding can help shift the question in both practice and research from particular elements (square, street, segment, or building) towards an approach that incorporates contexts and systems. It further allows an approach where variations in ‘liveliness’ or ‘centrality’ are coherent, conceptual parts of the intervention rather than an issue or left unaddressed. Such an approach allows better for making sure that the positive contributions of centres can integrate with its surroundings instead of being confined to a particular street or place, and also that there is affordance for dynamic growth and shrinking processes of a variety of activities. It can be noted that a lot of planning today is operating with a ‘point’-thinking (possible scattered points), or at best a ‘line’-thinking (e.g. ‘place-making-initiatives’; Gehl, 2010). Ironically, shopping initially borrowed features from the city and according to McMorrough (2001, 194): “Through an evolving series of processes, shopping has come to constitute urbanity” (2001, 194).

To reiterate: ‘points’ are not very efficient in creating urban life outside of itself, in a neighbourhood or in a district. Points instead tend to draw activities away from the surroundings, leaving streets in the proximity rather quiet. Hence, subcentres with a point-logic may provide service and enables access to certain amenities but is weaker in providing spaces for interplay or exchange. Subcentres with a line-logic do not concentrate movement as strongly as a ‘point’ does and the linearity distributes access to certain amenities and services more efficiently to its surrounding. An advantageous effect with the ‘line’ compared to the ‘point’ is that the attraction of each individual point decrease in importance, rather, the points collectively builds up an attraction that is at play. This opens for a larger variation of actors; also less strong actors/businesses are able to establish in a favourable location. However, the constraints of the lines lie in their linearity; as McMorrough (2001) points out, the affordance for variety and dynamic adaption is much greater in a field, and such variance and adaption, we argue, are important for a diverse but integrated society. A sharp non-connecting interface to the neighbouring areas has a segregating effect rather than a linking effect that limits the social interplay locally. Such fragmentation is similar to what Peponis et al. (1997, 344) highlight in the reasoning around what discourages traverse circulation and difficulties in understanding a larger scale based on urban organisation locally. The assumption that ‘areas’ are created by well-defined boundaries has been questioned within space syntax theory and instead it is found that centrality that pervades at different scales is more likely to support what Peponis et al. call ‘area-sation’ (1997). Also emphasised by Hillier (1996) is that the breaking of the interface between inhabitants and strangers corresponds to ‘disurbanism’ and is related to impaired potential for ‘liveliness’. In line with this, Hanson argues that ‘estate morphologies’ (weakly spatially integrated in its surroundings, meaning no line nor field conditions) implies a ruptured interface at many levels, both spatially and socially (Hanson 2000, 114, 117). ‘Points’ appear as aggregations in the urban fabric but are weakly integrated in its context with the effect of limit co-presence to these nodes and with poor or no ‘spill-over-effect’ to its surroundings. This does not only concern itself with amount of co-presence, however, but with who might be co-present with whom, where, and who might visit which part of the city. Two ‘lively points’ may be more segregating than one ‘calm field’. This taken together appears to be an unfavourable situation for a city that strives to connect the city and its citizens and decrease fragmentation, both from a spatial and a social perspective. Our investigation shows that it is possible to elucidate where areas or centres act as points, lines and fields by careful configurational analysis, instead of being confined to observable boundaries or typological interpretations.
We argue that in order to reach the social goals formulated by the city and the region ‘field conditions’ are the most supportive. Field conditions provide both lively and quiet streets in close proximity and enable social relations to be less controlled and fields are likely to encourage a larger variation of everyday practices. Field conditions hence create non-correspondences argued to encourage a mixing of categories locally (Hanson & Hillier 1987). Ignorance towards the complex contextual conditions that configurative properties make visible, risk to mislead investments or interventions may be ineffective. We furthermore argue that a concept such as ‘field’ is able to respond to morphological and social character without reducing the question to a simplified understanding of geometric typologies. We conclude that (1) ‘Liveliness’ and distribution of liveliness is affected by how centrality is configurationally characterised, which (2) sets conditions for social life and activity including how liveliness can emerge but also how other social arenas and activities can find their place.
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ACCESS AND VITALITY IN THE PARANOÁ LAKE (BRASÍLIA, BRAZIL)

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ABSTRACT
This research aims at investigating vitality in leisure areas near urban water bodies and explores the relations that can be established between water bodies and the city. The theme is approached from a broad perspective and analyzes possibilities of fostering the appropriation of the shores by the population, by means of implementing morphological changes. The possibility of associating configurational variables to areas with greater vitality levels is thus the starting point for a discussion about how urban projects can create live spaces. The theory, methodology and tools of the Theory of Social Logic of Space are applied. The case study is Projeto Orla – an urban intervention project at the shores of Paranoá Lake, in Brasília, Brazil. Three research questions have been posed: 1) How does the lack of articulation between the city and leisure areas near water bodies affect the vitality of these spaces? 2) Can configuration be understood as a factor which contributes to the flow of people in the process of appropriation of these shores? 3) Which factors are responsible for the abandonment of some sites of Projeto Orla, even when the infrastructure was provided in accordance to the project? The results obtained for Paranoá Lake point to a disarticulation or lack of integration between the water body and the urban fabric as being the most marked aspect to justify low levels of vitality. Findings suggest the configurational aspect plays an important role in the urbanity of the case study, especially at the global scale.

KEYWORDS
Waterfronts, leisure areas, configuration, Brasília/Brazil, Paranoá Lake

1. INTRODUCTION
Several urban settlements have water bodies in its fabric or are adjacent to it and the vitality of waterfront spaces destined for leisure has sparked an ongoing debate. This paper, based on a master dissertation developed by Lembi (2015), aims to contribute to this debate and explores the role of spatial configuration in fostering such vitality. Projeto Orla, in Brasília/DF, was adopted as a case study. Spatial relations originating from morphological patterns are seen as a contributing factor to the dynamics of spaces in the city.

A crucial point in the dynamism of leisure spaces at the waterfront for urban life seems to reside in the articulation between cities and bodies of water, which is linked to characteristics of the location of the shores within the context of the urban system. In addition to the articulation between the parts of the whole, other aspects such as abandonment, underutilization, existence of residual areas, lack of infrastructure and fragile hierarchical position also seem to contribute to the lack of life in these spaces (for a further discussion, see Lembi, 2015).
Based on these premises, the research seeks to investigate the articulation between waterfront leisure spaces and the city. The analysis is carried out from a configurational perspective, implying the study of the relations between the parts that compose the urban system. The term “urban configuration” (Hillier and Hanson, 1984) is understood “not as a cluster of objects and forms-spaces distributed around the city, but as a set of articulated elements” (Medeiros, 2013, p. 102).

The mapping of local dynamics was incorporated to the procedures and has allowed the scrutiny of configurational data in order to discuss the synchronicity between the real and the potential performance. These elements were obtained from spatial modeling strategies based on Space Syntax. The focus of the interpretation is on the description of the system (axial and isovist representations), on the interpretation / quantification (processed data that result in measures or syntactic variables) and on the analysis of results / correlations (land use, street network, centralities, etc.), generated from city plans of Brasília and the blueprints of Projeto Orla.

The research aims to identify if the articulation between the city and the leisure spaces at the waterfront is decisive for the vitality of these areas and, based on the results, to define which “vitality variables” are associated with spaces of greater urbanity - which reinforces the exploratory nature of the research.

2. PROJETO ORLA

In the year of 1992, the then Department of Tourism of the Federal District – Detur, in partnership with the Brazilian Institute of Tourism – Embratur, hired the services of a consulting firm, TCI Planning, Projects and International Consulting Ltd., to carry out a feasibility study in an attempt to stop the continued privatization of the waterfront of Lake Paranoá and to bring Brasília to the regional, national and International tourism scene. The studies comprised the document Tourism Framework and Structuring Plan of Brasília – Projeto Orla (Figure 1) intended to qualify and promote the touristic, economic and cultural exploitation of the remaining free areas located at the shores of Paranoá Lake, providing free access to the waterfront. It would be a broad project for the entire margin area developed in partnership with the private initiative, with the purpose of establishing quality public spaces for leisure.

Figure 1 - Map of Projeto Orla (general plan), Activity Report - Projeto Orla - 1998 (with adaptations). Source: Botelho (2003, p. 40).
In 1992, Projeto Orla envisaged the implementation of ten sites of activities: (a) Site 1 – Pontão do Lago Norte; (b) Site 2 – Complexo da Enseada; (c) Site 3 – Complexo Brasília Palace; (d) Site 4 – Parque do Cerrado; (e) Site 5 – Marina do Paranoá; (f) Site 6 – Centro de Lazer Beira Lago; (g) Site 7 – Parque da Ciência e Tecnologia; (h) Site 8 – Centro Internacional e Cultural; (i) Site 9 – Parque Aquático; (j) Site 10 – Praça das Nações, with an estimated area of 780,000 m². At the same time, a group composed of representatives of various GDF bodies was appointed to follow the drafting of the proposal.

The project was restructured in 1995, so that leisure would be associated with both the development of economic activities with the generation of jobs and income and the democratization of access to the lake. Under the supervision and coordination of Terracap and the then Secretary of State for Urban Development and Housing – Seduh, the action then was carried forward, comprising eleven Sites – (k) Site 11 – Pontão do Lago Sul –, where various uses and activities were planned, including leisure, entertainment and lodging.

To interconnect the eleven sites, four circulation systems were proposed, the first one being the Lucio Costa pedestrian walkway, which would be the defining and structuring element of these spaces at the waterfront; the second a cycle path, which should run parallel to the avenue, but could sometimes move away from it and go through more isolated areas; the third option would be a low-speed vehicle (Light-weight Vehicle on Wheels - VLP) connecting the sites by an alternative route, which at times would run near the lake’s shores; and finally, the public marinas and small piers to serve the water transportation.

Although the objective of Projeto Orla was, since its inception in 1992, to qualify and integrate the remaining public spaces, to promote the articulation between the city and the lake and to foster the free and public use of the waterfront, it has not been able to achieve this to the present day. Due to lack of political will, the project was only partially implemented. In addition, the circulation systems initially proposed for integration between the eleven sites was never implemented (for further details about the Projeto Orla, see Lembi, 2015).

3. THEORETICAL, METHODOLOGICAL AND TECHNICAL ASPECTS

3.1. THEORY / CONCEPTS

The conceptual scope adopted is based on the Theory of Social Logic of Space or Space Syntax (Hillier and Hanson, 1984; Holanda, 2002; Medeiros, 2013), which provides strategies for the investigation of spatial relations based on the principle of configuration. It is assumed that the reading of the urbanization process and the dynamics/vitality of the spaces that result from it can be better understood from its configurational reading.

3.2. STAGES OF RESEARCH

Phase 01 (Configurational Modeling) – Production of configurational modeling from Space Syntax, with focus on the description of the system (axial and isovist representations), interpretation/quantification (processed data generating measures or syntactic variables) and analysis of results/correlations (land use, street network, centralities, etc.), derived from city plan of the city of Brasilia and the blueprints of Projeto Orla. The interpretations were developed in three stages: level 1 – area corresponding to Brasilia’s Pilot Plan and the regions called Lago Sul, Lago Norte, Paranoá, Varjão and the Setor Habitacional Taquari, altogether called Sistema Lago (Lake System) (Figure 2); level 2 – the Federal District and level 3 – Brasilia’s Metropolitan Area – AMB.
Phase 02 (Mapping of Local Dynamics) – Mapping of the local dynamics to contrast with configurational data, in order to verify real and potential performance based on the modeling. The data collected allowed us to identify the sites of greatest movement in each of the sites of Projeto Orla, in order to search for the correspondence between the use of spaces, where there is a greater concentration of people or activities, and potentially more attractive areas.

Phase 03 (Consolidation of Results and Discussion) – Articulation of the findings, to contrast the results from the scrutiny of the object of study with the corresponding research questions.

3.3. TOOLS / INSTRUMENTS

There are three Space Syntax representation strategies used in the study of urban settlements and two of them are relevant to the present research: the axial map and the visibility/izovist map. According to Medeiros (2013, p. 149), each of these strategies is related “to an aspect of how individuals experience and use space: people move along lines (linear representation), group into convex spaces (convex spaces) and dominate a visual field from any given point (izovist)”.

3.4. OBJECT OF STUDY AND CONFIGURATIONAL MODELING

For the study of the Projeto Orla, 13 areas were explored comparatively, (11 sites, and two places called Calçadão da Asa Norte and the Ermida Dom Bosco). Subsequently, five areas were selected to map the local dynamics, aiming to represent extremes of little or intense vitality of the public space. Two of them are part of the original ten sites created in 1992: Brasília Palace Complex (Site 3) and Centro de Lazer Beira Lago (Site 6). The third is the Pontão do Lago Sul (Site 11), incorporated to Projeto Orla in 1995. The others were incorporated into Projeto Orla during the administration of Governor Cristovam Buarque: Calçadão da Asa Norte and Ermida Dom Bosco Park.

In the areas described, the axial configuration and visibility tools were applied, focusing on two different situations: the first focus is the pedestrian, therefore the tools were applied to the official pedestrian pathways, that is, paved sidewalks (pedestrian map); the second focus is the automobile, so the tools have been applied to vehicle parking lots and streets (vehicle map).
4. DISCUSSION OF RESULTS

The variables were initially developed for 13 areas in order to measure connectivity, global integration and local integration solutions. Next, the axial maps and visibility maps were compared with the data obtained in the mapping of the local dynamics of the five selected areas of interest, to include (a) the main attractive element; (B) accesses; (C) identified uses; (D) identified profiles; (E) state of preservation and maintenance; and (f) safety.

The comparisons carried out resulted in a set of findings, summarized in Tables 1, 2 and 3 and consolidated as follows.

COLOR SCALE - PERFORMANCE / VALUE (Tables 1, 2 and 3)

Table 1 - Synthesis of the axial measurements referring to access routes to the 13 areas (Lake System)

1 The colors correspond to the values obtained, comparatively, for each one of the access routes to the thirteen areas (11 sites and 2 additions). The warmer the color, the higher the value; the colder the color, the lower the value.
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Table 2 - Synthesis of axial and visibility measurements for pedestrian pathways for 5 selected areas (Independent Systems)  

For the axial measurements, we completed the table with a range of values, according to the variable and each of the five areas of interest. The warmer the color, the higher the value; the colder the color, the lower the value. However, for the variable total number of system lines *, the chromatic scale is inverted. For the measurements of visibility, we completed the table with a range of colors, according to the variable and each one of the five areas of interest. The warmer the color, the greater the correspondence between the variable and the actual movement, the colder, the less the correspondence. Therefore, in this case, the analysis is qualitative, since we do not explore the numerical measures, but rather the synchronicity between variables and movement of pedestrians and vehicles. This way, it is a first attempt to identify if one area has more or less synchronicity than the other. Blank cells indicate unprocessed variables, which we assume is a limitation of the Depthmap® software for analyses that require greater robustness. NA indicates a situation is Not Applicable.
## Access and Vitality in the Paranoá Lake

### Independent Systems (Vehicles)

<table>
<thead>
<tr>
<th></th>
<th>Complexo Brasília Palace (Polo 3)</th>
<th>Centro de Lazer Beira Lago (Polo 6)</th>
<th>Pontão do Lago Sul (Polo 11)</th>
<th>Parque Ermida Dom Bosco</th>
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<td>a) Visibility Graph</td>
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**Table 3** - Synthesis of axial and visibility measurements for vehicle lanes and parking lots for 5 selected areas (Independent Systems)
Most sites have similar values for measures of connectivity, global integration and local integration. Within the selected areas, however, Complexo da Enseada (Site 2) and Calçadão da Asa Norte stand out, both represented with warmer colors (red and orange) in Table 1. Marina do Paranoá, on the other hand, shows the worst of the performances, with a predominance of cold colors in the three variables. In the comparative global perspective, however, they are spaces that tend to the homogeneity of performance.

These values indicate that the sites in general are poorly connected, especially when compared to those of the EPIA and the Monumental Axis (the two most emblematic avenues of the urban system, one for its intense flow and the other for its civic character and for how it symbolizes the notion of a capital itself), and in some cases with the average of the Lake System and the Federal District. The result correlates to the urban makeup of Brasília itself (understood within the scope of the Federal District, but which also reproduces the discontinuities within the Pilot Plan), which is associated with a labyrinthine and fragmented configuration, making accessibility difficult, as shown by the configurational readings (Holanda, 2002 and Medeiros, 2013). The sites, therefore, are also fragile areas integrated to the immediate urban fabric but far from the Central Zone of Brasília and the EPIA. As a result, Lake Paranoá is not part of the integrating core of the city.

Still for the Lake System, but now only considering the access streets of the five areas of interest, Calçadão da Asa Norte stands out with higher values of global integration. It is the most easily accessible place from all the axis of the system analyzed, which perhaps explains in part why it is one of the areas with greater vitality in the sample. It is worth mentioning that in the vicinity there are high flow streets which act as public transportation corridors, such as the Eixo Rodoviário and L2 North Avenue, facilitating wide access. In addition, the site has the highest values of connectivity and local integration R3. In the opposite end of the spectrum, Ermida Don Bosco stands out with low values of global integration, as can be seen on Table 1, therefore it is the most segregated site in the sample. Despite these unfavorable values, Ermida Don Bosco has values of connectivity above average and local integration R3, which points to the fact that it is internally well articulated, considering the immediate environment. Pontão do Lago Sul and Beira Lago have low values for all three measurements, generally below the average of the sites (In Table 1 the cooler colors predominate: shades of blue). However, all three areas have a considerable flow of people.

Complexo Brasília Palace (Site 3) has above average results for all three measurements (indicated with colors ranging from green to orange, in Table 1). However, among these five areas of interest, it is the one that appears to have the lowest concentration of people based on in loco observations. Despite the location of relatively easy access, local attributes do not contribute to the attraction and permanence of people: There are large empty areas, public equipment is lacking, and consolidated buildings in the vicinity or inside the site act as barriers, such as the flats located there.

Roughly, all these places show a moderate movement of people that fluctuates throughout the week, predominantly on weekends. In all cases, however, the configuration justifies a condition of isolation, which implies a lower vitality than it could achieve, given their arrangement in the urban system (global perspective of the city).

For the purpose of comparison, restricting the configurational modeling to the legal areas of the sites, the Independent Systems were evaluated (internal reading, including access streets). In addition to comparing connectivity, global integration and local integration variables previously explored for the Lake System, we also sought to establish their correlations (intelligibility and synergy). Three additional measures of interest were also generated from the axial maps: total number of lines of the system, average size of the axis and compactness (number of axis per area).

From the set of results, Calçadão da Asa Norte stands out from the other areas for the high averages of global integration, synergy and intelligibility (indicated in orange and red, in to Tables 2 and 3), both for pedestrian pathways as for streets and parking lots. Connectivity and local integration R3 measures, which relate to local interpretation, are similar to the average
of the other sites. This demonstrates that the configuration dynamics favors the movement of people, which, added to other attractions or attributes, such as free access, position in the urban system, and the numerous activities that this free access to the lake offers, would explain the great vitality of this area. On the other hand, Calçadão da Asa Norte has the lowest total number of lines, both for vehicles and pedestrians (indicated in red in Tables 2 and 3, since for this measure, higher values mean compromised performances, hence the inversion of colors), resulting in low values of compactness, which in turn is related to the small scale (it is the smallest of all the sites) and the extreme linearity of this system. However, the space presents the highest values for the criteria ‘average size of the axis’ for vehicles (Table 3) and the second largest for pedestrians (Table 2), which would somehow justify their high values of global integration, since larger axis more effectively cross the system and connect more parts of the whole, implying greater accessibility.

On the other hand of the spectrum we have Ermida Dom Bosco presenting the opposite characteristics, for both the pedestrian pathways and streets and parking lots, with the lowest values of compactness, connectivity, global integration, synergy and intelligibility among all areas. The local integration R3 value for pedestrian pathways is also the lowest of all the areas (all these measurements are indicated in dark blue in Tables 2 and 3). The place has the second largest total number of lines for the pedestrian pathways (indicated in light blue in Table 2, since for this measurement, higher values mean compromised performances, hence the inversion of colors), which reveals a structure of more labyrinthic pathways resulting from the large voids and discontinuities in the use of space. This situation leads to dispersion, which explains its low values of compactness (the placement in the physical site must be considered here). Ermida has significant values for the criteria the ‘average size of the axis’, both for pedestrians and for vehicles (green and orange, in Tables 2 and 3), but this does not result in an increase in overall integration. However, it should be mentioned that the site has a considerable movement of users on weekends and holidays, which is certainly associated with other aspects, such as the possibility of contact with nature, free access, contact with water, beautiful view of the city, etc.

The Brasília Palace Complex (Site 3), for both pedestrians and streets and parking lots, has the highest connectivity values (in red, in Tables 2 and 3). There are high averages in both systems (pedestrian and vehicles) for measurements of global integration, local integration R3, synergy and intelligibility (indicated in orange and red, according to Tables 2 and 3). However, the configuration dynamics do not coincide with the flow of people in this area, which appears to be the one with the least vitality. The findings indicate that performance is associated with other factors such as low values of compactness, both for pedestrian pathways and for the streets and parking lots (light blue and green colors, according to Tables 2 and 3), a product of a great predominance of voids. The reading of these measures, therefore, would not explain everything, since Calçadão da Asa Norte, which has a large flow of people, also has low values of compactness. Therefore, once again, the potential of the configuration seems to be underused, since there is a set of characteristics that end up pushing visitors away: lack of diversity of uses; an excessive number of barriers demarcating the site, and lack of public equipment such as benches, garbage cans, proper lighting throughout the area of the site.

Centro de Lazer Beira Lago (Site 6) has significant connectivity values, both for pedestrian pathways and for streets and parking lots (orange and green colors in Tables 2 and 3). It presents, however, low values of global integration, both for pedestrians and vehicles (indicated in light blue in Tables 2 and 3), which are only not lower than the values for the Ermida Dom Bosco. It has significant numbers of local integration R3 only for the pedestrian pathways, since for the streets and parking lots it has the lowest values (indicated in dark blue, in Table 3). It comes in second to last for synergy, both for the pedestrian map and for the vehicle map (indicated in light blue in Tables 2 and 3), once again, only better than the Ermida Dom Bosco. Despite the aspects mentioned above, Centro de Lazer Beira Lago has significant values of intelligibility, mainly for the pedestrian map (green color in Tables 2 and 3). It also presents the second largest value of compactness, both for pedestrians and for vehicles (indicated in orange in Tables 2 and 3), however it presents more irregular fabric, considering the low values for the measurement of the average size of the axis of this system (light blue in color in Tables 2 and 3).
Pontão do Lago Sul (Site 11) has significant connectivity and global integration values and the highest local integration value for vehicles and the second highest for pedestrians (red and orange colors, Tables 2 and 3). The site also presents significant values for synergy, mainly for the pedestrian pathways (in green, Table 2), but it is but the last place for intelligibility, both for the pedestrian map and for the vehicle map (light blue, Tables 2 and 3). It has the lowest value for the criteria ‘average size of the axis’ (indicated in dark blue in Tables 2 and 3), which reveals the more irregular layout of its pedestrian and vehicle paths. However, it presented the highest values for the criteria ‘total number of lines in a system’ (indicated in dark blue in Tables 2 and 3, since for this criterion higher values mean compromised performances, hence color inversion), and compactness (in red, in Tables 2 and 3), for both pedestrians and vehicles, which reveals a more balanced relationship between fulls and voids.

We also independently analyzed each of the five areas which were the focus of this study, called Independent Systems. Therefore, from the axial maps, both for the pedestrian pathways (pedestrian map) and for streets and parking lots (vehicle map), we obtained three variables (connectivity, global integration [HH] and local integration [HH] R3). In this case, in addition to the quantitative interpretation (numerical measures), we tried to evaluate the degree of correspondence between variables and movement of pedestrians and vehicles.

In general, when analyzing connectivity measures, global integration and local integration R3, both for the pedestrian map and for the vehicle map, there is a good correspondence between pedestrian flow and vehicles and the axis with the highest values for the measurements. Correspondence is believed to be associated with the small scale of most of these systems. Calçadão da Asa Norte is the site in which correspondence occurs to a greater degree, both for pedestrian paths and for streets and parking spaces. This system is characterized by its small scale, extreme linearity and uniformity of streets and pathways. Complexo Brasília Palace also showed a good synchronicity, which is believed to be associated with its great orthogonality, which results in higher values of connectivity and integration, as well as higher values of synergy and intelligibility.

For the visibility measures, Tables 2 and 3 were filled with a range of colors, according to the variable and each of the five areas of interest. The warmer the color, the greater the correspondence between the variable and the actual movement, the colder, the less the correspondence. Therefore, in this case, the analysis is qualitative, since we are not talking about numerical measures, but about the synchronicity between variables and movement of pedestrians and vehicles. Furthermore, it is not necessary to have all the colors of the chromatic gradation: if all the sites reached a high correspondence between the configurational performance and the movement, they would all be represented in red.

The prevalence of cold colors over warm one is easily noticeable in the tables, for pedestrians as well as for vehicles, mainly for the vehicle map, which indicates that to a great extent there is little synchronicity between the variables of visibility and the real movement. At the local level, the potential of path configuration is underused. This shows that other factors, such as the presence of the lake, are more determinant than configuration in conditioning of the flow in Projeto Orla. Calçadão da Asa Norte and Centro de Lazer Beira Lago are the sites where correspondence occurs to a greater degree, especially for pedestrian pathways. These two systems are characterized by (a) their small scale, the smallest among the others analyzed (69.64K sq.m and 101.92K sq.m. respectively); (b) homogeneity of the path network and also (c) a rigidity that conditions the displacements.

5. CONCLUSIONS

The study points out that a series of configurational attributes (axial and visibility measurements) present a similar performance for most sites interpreted (micro level). Internally, connectivity and global and local integration have a strong relationship with movement (regardless of its intensity). It is worth mentioning that the configuration evaluated through Space Syntax is always potential, as the literature demonstrates, being traditionally compatible with reality (Hillier and Hanson, 1984; Holanda, 2002; Hillier, 2007; Medeiros, 2013). In the areas investigated
in the case study, this potential sometimes corresponds to reality, sometimes not (Tables 2 and 3). When there is a correspondence there is a synchronicity between configuration and movement, and when there isn't, other factors are a priority for the conditioning of the flow, including the state of conservation of the equipment, the presence of furniture, sense of safety, etc.

Therefore, it is believed that the abandonment or non-appropriation - understood here by the diversity of users - of areas of Projeto Orla, even when the infrastructure was offered / executed, is much more related to the fact that all these areas are not accessible to the city as a whole, that is, the sites have a low configurational performance from a global perspective (macro level). Other clearly configurational issues are related to the strong presence of voids in Brasília, which promotes significant discontinuities in the fabric, leading to poor performance. A complementary morphological aspect is the land use: for this reason, the areas around the sites are almost always monofunctional, hampering the diversity of people (although residential use is recurrent around some of the areas, which in principle would be positive).

The research presented the applicability of Space Syntax in the study of these peculiar areas, which made it necessary to adopt a series of specific criteria in the application of the analysis tools. In addition, it has brought contributions that may be relevant to the field of project and the urban design of open public spaces on the waterfront by confronting the spatial dynamics of movement and use and occupation, between real and potential performance obtained from modeling. The action seems to provide support for designing spaces along the shores of water bodies that attract greater vitality and provide the conditions for people to spend time.

A conclusion reached is the interpretation that the connectivity and integration variables are both, the clearest to investigate the subject, and the more easily obtained, which is relevant for expedited analyses - the others seem to derive from these two, with slightly different results, but pointing to an approximate performance.

In fact, there is criticism that the results of the application of the Space Syntax tools are better for dense structures and are worse for empty structures, but the literature is vague in the discussion. Therefore, what the work provides as contribution is to prove that a certain set of variables is not actually applicable in this context of the “empty” city, unlike others that apply even in this case. The findings reinforce the experimental character of the research, proving a set of presumed but unproven perspectives.
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HOW CENTRAL IS THE RAIL STATION?

Incorporating Rail Centrality with Development Potential

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ABSTRACT

The study presented in this paper offers a methodology for the assessment of development potential around rail stations, by taking into account the importance of each rail station in the global rail network and the local urban fabric in the rail station’s vicinity. To achieve this goal this methodology incorporates intercity rail centrality along with local centrality measures relevant for non-motorized transport. The case study explored here is the Israeli railway passenger network spanning from the southern city of Beer Sheva up to the northern edge of the Haifa Metropolitan area.

Following earlier efforts for a multi-modal transit analysis using space syntax (Gil, 2012; Law et al., 2012), this study aims to combine centrality regimes at different scales, therefore providing the capability to assess a place potential for development based on its multi-modal accessibility. Combining the values of different centrality regimes allows for identification of areas that have high centrality values at different geographical scales concurrently. This methodology highlights the locations of rail stations with good local accessibility ripe for development. Moreover, this process may also be used in the planning of new rail stations and in choosing their locations.

KEYWORDS

Israel, Train Stations, Rail, Transit-Oriented-Development, Space Syntax

1. INTRODUCTION

This study addresses the central concern about how to combine expansive large-scale transport infrastructure with sustainable urban growth, by maximizing opportunities for Transit-Oriented-Development. This paper presents a specific but as of yet under-exploited contribution to this urgent issue by employing and combining the configurational approach of space syntax at different geographical scales. This configurational approach has been successfully applied in various urban planning settings (Karimi, 2012; Lerman et al., 2014), but is yet to be expanded as an evaluation tool to aid in planning of national-scale rail projects.

The central hypothesis is that space syntax methodology, through its proven ability to capture pedestrian movement (Hillier et al., 1993; Hillier and Iida, 2005) and its capacity to handle large spatial systems (Serra and Pinho, 2013; Serra et al., 2015) can contribute to a better understanding of how global and local mobility flows can be integrated. The kind of intermingling of global and local movements addressed here is especially acute in train stations (Bertolini, 1996). Therefore, this study aims to quantify the centrality of stations related to their position in the national rail network and combine it with their local centrality in the surrounding urban fabric. For this amalgamation the node-place model of Bertolini presents an excellent theoretical framework.
The node-place model measures rail stations by their accessibility (the node-index) and the intensity and diversity of activities in their area (the place-index). Through the combination of these measures it categorizes rail stations into balanced and unsustained stations. For balanced stations the node-index and place-index are somewhat similar (a further distinction of stressed and dependent stations is also given), while for unsustained stations there is a mismatch between the node and place indices, reflecting either high accessibility with low amount of activities or high amount of activities compared to the accessibility level. To easily assess the accessibility of rail stations (the node-index in Bertolini's model) using space syntax measures, this study relies on the directness of the rail network but does not deal with the actual frequency and speed of the trains.

Earlier work (van Nes and Stolk, 2012) assessed train stations location and potential under concurrent centrality measures at different geographical scales. Our approach aims to capture the stations’ development potential with a single measure which can effectively represent the intermingling of global and local movements. Such a benchmark can help to better assess the potential development around existing and proposed train stations and support decisions makers in locating new stations and improving existing ones.

The rest of the paper is organized in the following way: the next section presents the methods and the case study on which they were applied. The section afterwards shows the results of the proposed methodology, while the final section concludes with several suggestions for further research and applications of space syntax for rail analysis and planning.

2. ANALYZING RAIL STATIONS’ CENTRALITY AND IMPACT

This research focuses on Israel’s national rail network. In order to assess the centralities of the rail stations the entire Israeli road network was modelled with segments adapted from a road centre line map (taken from Open Street Map). Earlier studies combining rail transit and road network analysis have differed on the exact method used to attach the rail stations and segments to the road network. Gil (2012) used axial lines and added axial connections to represent London’s rail network. Another study based on segment analysis (Law et al., 2012) added direct segments between London’s rail stations as well as connecting segments to represent changes from street to rail platforms. This study is based on angular segment analysis (Turner, 2007) and applies a similar approach to the one used in the latter study mentioned above. However, the method used in this study is a bit simpler. In this study, each rail station was located as a node on the end point of its nearest segment in the road system, or at the intersection of two segments which lead to the station’s entrance (Israeli train stations have at most two entrances). Afterwards the rail network segments were added on top of the road network, connecting the different train stations according to the actual routes available at peak hours.

As mentioned above, this study uses segment representation of Israel’s road map including its rail network. The analysis of the angular distance (least cumulative angle measure) between the segments provides a number of indices of the network, which describe the centrality of a given segment. Space syntax analysis produces several such measures, most prominent among them are integration and choice (or closeness and betweenness in graph theory). Integration indicates the closeness of a segment to all the other segments in the system. This reflects the segment centrality or to-movement potential. The Choice measure reflects the likelihood of through-movement for a given segment as it evaluates a segment usage in the shortest paths among other segments in the system. Both integration and choice measures can be calculated on a global scale for the entire system and at a local scale, limited by a specific radius. A higher radius indicates a larger extension of the network. For further information on the calculation of these measures and the relevance of angular measures for urban movement please see: Hillier and Iida, 2005.

Overall, the national road map of Israel consists of 224,657 segments covering a length of 23,544 kilometres. In addition there are 54 rail stations and 62 segments connecting them covering a passenger rail network of 621 kilometres. Since this analysis focuses on combining large scale infrastructure with local urban conditions an exact configuration of pedestrian only paths,
bridges and underpasses must be carefully represented around each station. So, while tracing the national road network, a special attention was given to the rail stations’ surroundings and their exact modelling. Figure 1 shows Israel’s road map with the rail segments superimposed on it.

To capture the nature of long rail distances, an angular choice measure with a very large radius was used to create a measure which quantifies the Station Power (SP). The SP value is calculated by summing the choice values for all of the rail segments meeting at a station. This calculation gives higher values to stations where multiple lines meet and where train interchanges occur.

Figure 1 - The national road map of Israel with the rail segments (in yellow).
The specific radius used for the evaluation of the SP measure is derived by applying statistical correlation between the SP values of the rail stations and their corresponding total daily passenger boarding numbers. In addition, high choice values (with a large radius) tend to highlight rail segments and motorized highways. Therefore, to better reflect commuting rush hour and speed difference between rail and (clogged) highways – the calculated choice value is multiplied by a factor of three for all rail segments in the national road and rail network. This calculation is based on rail relative efficiency compared to vehicular movement during rush hour. During rush hour average rail speed in Israel may be up to ten times as much as vehicular traffic speed, depending on the specific road segment (For reports on intra-urban rail and vehicular speeds in Israel see: Ronen, 2011; Bar-Gera et al., 2015). For the purpose of this study we simplified the rail advantage by multiplying the entire rail network by the same factor, but further studies with an extended data set may multiply different rail segments by different factors (depending on the actual average difference between vehicular and rail speed along these segments).

The topmost choice values are concentrated on the segments with expected large flows of long-distance movements, including the segments that represent the rail tracks themselves. Since these segments are not available for direct urban development and do not exist in the pedestrian movement network we need to spread the impact of each station’s centrality around it. For this we take the station’s SP value and spread it to all the segments in the pedestrian shed of 700 metres around each station, representing the potential area for pedestrian-based development around each station (c.f. 700 metres usage in: Bertolini, 1999; Vale, 2015).

To assess the potential for development based on non-motorized movement in the vicinity of the train station we need to calculate a local angular integration value that is representative of non-motorized movement. For this we have used angular integration at the radius of 1,250 metres, which proved to have decent correlation values with pedestrian movement in several other studies in Israel (c.f. Lerman and Omer, 2016, p. 9). This integration radius value is somewhat arbitrary at this point and may be different under different conditions and areas.

To quantify the actual combination of large-radius choice measure along with the low-radius integration measure, a multiplication of the expanded choice value with the local integration value was done for all the segments in the system. The resulting multiplication values allow for locating segments that have both a high choice value, which pertains to large global scale movement flows, and a high integration at the local scale, meaning prime conditions for pedestrian movement and destinations.

To summarize, the general algorithm used to combine large scale intra-urban rail movement together with low scale local pedestrian movement, while focusing on potential development in the immediate vicinity of the rail station is as follows:

1. Calculate the sum of the angular choice measure for the rail segments at each station. The radius used should be extensive to represent rail movements probably over 50 km.

2. Correlate the choice sums at different radii versus the daily boarding numbers at each station to find the radius that has the best correlation. For each station the sum of the angular choice at the best fit radius represents the station centrality to a certain degree and we’ll call this value Station Power (SP).

3. Multiply the SP value by a factor to better represent the rail advantage versus road and spread this value across a pedestrian shed around each station, encompassing the development area that has the most potential to be affected by the train station.

4. Calculate a local angular integration value that best captures local movements for the entire system. Typically, this should be done with a radius lower than 2,000 meters.

5. Now multiply the choice value with the best fit radius and the local integration value for all the segments in the system. This combined value is the Rail-Development Potential (RDP).
6. Finally, we have a map where each segment has an RDP value calculated. This map requires further analysis in order to evaluate how well this value captures real development potential and where there are gaps in the analysis or in maximizing the development potential.

3. RESULTS
In order to assess the validity of the choice measure we have calculated the correlation coefficient between the SP measure (the sum of the choice values for each station as described previously) and the passenger boarding numbers for each station. The radii range for the SP calculation was set from 50 km up to 120 km with jumps of 10 km in between. The actual boarding numbers values were supplied by Israel Railways and represent an average weekday during the first quarter of 2016. Since both the choice values and boarding numbers have heavy-tailed distributions (most stations have low values and few have very large values), we have normalized both of these variables using the natural logarithm. The highest correlation coefficient achieved was with SP based on choice measure at a radius of 100 km where the log-log bivariate correlation produced an r-square value of 0.35, which was statistically significant with P < 0.01.

This correlation coefficient can (probably) be improved upon with further analysis. One of the major problems with the SP calculation is related to edge effect. Major stations at the edge of the system tend to have low SP value because they have a single rail link, yet a few of them have relatively high boarding numbers. This might happen because for many people (especially those living beyond the edge of the rail system), the edge stations are the best connection to Tel Aviv CBD, which is located at the centre of the railways system. For example, Beer-Sheva central station has over 8,000 boarding passengers per day making it the 12th most use rail station in the system. Yet, in terms of SP it is third from the bottom (placed at 52 out of 54 stations). In order to test the correlation without these edge stations we removed from the dataset three stations (Beer-Sheva Centre, Modiin Centre and Nahariya) which are all edge stations with relatively large numbers of passengers. The resulting r-square value between the SP based on choice at 100 km radius and boarding numbers without these three station is markedly higher and stands at 0.46 (also statistically significant with P < 0.01). Therefore, further work on the SP calculation especially for edge stations can improve the validity of the method and model presented here.

Figure 2 shows the Israel road and rail map with a choice 100 km measure. The segments with high choice values tend to be either rail segments or motorized highway segments. Figure 2a shows the original values while Figure 2b shows the same map with the choice values for rail segment multiplied by three to indicate a rail advantage over road (especially during rush hour commute). Figure 3 shows a close-up of the two largest metropolitan areas in Israel – Tel Aviv and Haifa. In figure 3a the original choice values at a radius of 100km are shown, while in figure 3b the choice values for rail segments are multiplied by three, therefore allowing them higher values than the rest of the system segments. In the close-up of the Tel Aviv metropolitan area it can be seen that this multiplication lowers the relative choice values of motorways 4 and 6 compared to the rail segments.

The SP measure, which is the summation of the choice values of the rail segments that intersect it, displays a heavy-tailed distribution. Thus, in the Israeli context most stations have relatively low power values (lower than the mean of the power values for all stations) and few stations have very large power values. In order to better visualize this kind of distribution the head/tail breaks algorithm was used (Jiang, 2013). This algorithm breaks a heavy-tailed distribution in a deterministic fashion by partitioning all the data values around the mean into two parts and continuing the process recursively until the head part values do not exhibit a heavy-tailed distribution.
Accordingly, the 54 rail stations were divided into the following three categories (shown in Figure 4):

1. High power stations – five stations which account for 9% of the stations.
2. Medium power stations – ten stations which account for 19% of the stations.
3. Low power stations – thirty nine stations which account for 72% of the stations.

Figure 2 - Choice values at 100 kilometres radius for Israel road and rail network. (a) shows the original values, while (b) shows the same map with rail segment choice values multiplied by three.
Figure 3 - Choice values at 100 kilometres radius for Tel Aviv and Haifa metropolitan areas. (a) shows the original values, while (b) shows the same map with rail segment choice values multiplied by three.
Figure 4 - A map of the Station Power (SP) measure for the entire passenger rail network of Israel. On the left is a close-up of the central rail corridor passing through Tel Aviv.
Afterwards, the SP measure of each station is spread among all the segments within its 700 meters pedestrian shed. Thus, each segment in the close vicinity of a rail station gets its value of choice at 100 km radius replaced with the SP value of that station. For the pedestrian movement potential we have used angular integration with a radius of 1,250 metres as a proxy for pedestrian movement potential and hence a proxy for intensive multi-modal development. Figure 5 shows the map of angular integration with a radius of 1,250 metres for the entire road system of Israel. Figure 5a shows the values for the entire system, while figure 5b shows close-ups of the two largest metropolitan areas – Tel Aviv and Haifa. This figure shows that the best potential for pedestrian and multi-modal oriented urban development lies at the old centre of Tel Aviv, which is indeed the case and where the financial quarter of Israel is located. This area has far more multi-modal development potential compared to the rest of the system. Figure 5 also highlights the older urban centres in Israel both in Tel Aviv suburbs and in other parts of Israel.

Finally, in order to combine large scale rail accessibility with low scale pedestrian accessibility, a multiplication of the choice value representing long movements with the integration value representing short movements and destinations is done for the entire system of Israel. Figure 6 shows the map of the RDP measure for the entire map of Israel. Figure 7 shows a bigger close-up of the central section with the stations that have the highest power values. It can be seen that the area around HaHagana station at the southern part of the city of Tel Aviv enjoys the highest RDP value, since it has a very central rail station combined with a good local urban road network around it. Another highlighted location is the area around Yoseftal station, which lies between the municipalities of Holon and Bat Yam just south of the city of Tel Aviv.

When super-imposing the SP map (Figure 4) on the pedestrian movement potential map (Figure 5), it can be seen that several of the train stations with the highest global accessibility in the entire system are located in areas with poor local accessibility and therefore low RDP value. This is especially true for Holon station (highlighted in Figure 7), where the entire surrounding area is underdeveloped, although the station enjoys high accessibility in the rail system.

This fact is also evident in the passenger boarding numbers of Holon station which has only 1,600 boarding passengers each day, a very low number when compared to the other centrally located stations (The central stations in Tel Aviv CBD handle around 50,000 boarding passengers per day, while medium size stations manage about 10,000 boarding passengers per day). This discrepancy between poor local accessibility and high global accessibility means that there is probably high potential for intense urban development around this station. Both of the stations mentioned earlier (HaHagana and Yoseftal stations) as well as the Holon station represent somewhat unsustainable station areas in Bertolini’s model, where high accessibility is not accompanied by similarly high land use intensity and diversity.

In order to truly assess this model correspondence to the actual development a correlation between this calculated RDP measure and the actual land use intensity and diversity should be done. Areas where the land use development lags behind the accessibility potential should be looked into in order to understand and possibly implement steps to improve conditions for rail-oriented development at these locations.
Figure 5 - The map of local level integration for the entire Israeli road network: (a) shows the entire map; (b) shows a close-up of the largest metropolitan areas – Tel Aviv and Haifa.
Figure 6 - The Rail-Development Potential (RDP) map for the entire Israeli rail and road network: (a) shows the entire map; (b) shows a close-up of the largest metropolitan areas – Tel Aviv and Haifa.
Figure 7 - The Rail-Development Potential (RDP) map for the most centrally located stations in Tel Aviv.
4. CONCLUSIONS

This paper presented a method to analyse rail station centrality and development potential using space syntax configurational approach. At the heart of the proposed method lies the combination of global flow accessibility (represented by an angular choice measure with a high radius distance) with local scale centrality (represented by an angular integration measure with a low radius distance).

Several limitations and proposed improvements to this study are put forth. This study has not used the actual frequencies and speed of the trains. To better represent rail superiority versus automobiles during rush hours, a simple multiplication by a factor of three for all of the rail segments choice values was applied. This altering of the system can be made more accurately based on real-world data with high resolution. Another incompatibility is related to the fact that several of the stations with the highest SP values have medium-level boarding numbers, yet we suspect that these stations are used heavily for train changes (especially the University and HaHagana stations in Tel Aviv where multiple lines meet and each of the stations has about 18,000 passengers boarding per day). This may mean that the stations with the highest SP measures have actually more people moving through them than reflected by the passengers boarding data, thus allowing for more retail development inside their terminals.

The case study used here was the Israeli railway network providing a relatively small national analysis. Further studies may assess larger road and rail networks, yet these assessments may be limited by the computational demands of larger systems. In addition, this study relied on the Open Street Map of Israel, which may have its own inaccuracies. Validating these results on an officially certified map would help assess their validity. As was mentioned before, this method did not take into account actual land use intensity and diversity existing around the train stations. A further step in improving the kind of analysis presented here would be to include and correlate space syntax accessibility measures (such as the SP measure and the RDP measure) to actual land use.

When revisiting Bertolini’s node-place model (Bertolini, 1999) and this method’s relation to it, we conclude that space syntax accessibility analysis at multiple scales can improve Bertolini’s model and especially give it some kind of standardization. Furthermore, the relative quickness of space syntax analysis (the need for just one good map and not multiple databases) may shorten the time needed for this kind of analysis. Currently, accessibility analysis relies on elaborate time tables of multiple transit means, which makes the calculation needed non-standardized and cumbersome because of the amount of data required.

The real potential for the application of this kind of method in real world planning lies in its relative quickness and identification of rail stations where there might be a large potential for development, yet this potential is somewhat hidden. In the case presented in this paper, three train stations (Holon, HaHagana and Yoseftal stations) exhibited measures which imply that these stations’ potential for transit-oriented-development is not fully realized. Furthermore, this kind of analysis may help in determining future stations locations or re-locations of existing stations to better capture and induce urban development potential. At times, in order to develop a station area, various infrastructure investments must take place to free the valuable land. This model can help in making these costly decisions.

In addition to rail network analysis, the method presented here applies an innovative combination of space syntax measures at different radii to make a single measure of development potential (referred to as RDP measure in this paper). In this case the combination took a choice measure at a large radius and combined it with an integration measure at a low radius. Other and more complex combinations may come to mind in order to assess alternative centrality regimes together. For example, combining motorized centrality may be achieved by adding a medium centrality radius into the mix. These kinds of combinations may improve assessment and visualization of complex transport interchanges both existing and planned. The visualization of the combined transportation means using a single measure is a powerful tool for policy making and for further integrating space syntax in actual urban and transport planning.
ACKNOWLEDGEMENTS

We dedicate this paper to the memory of Mayor Pinhas Zoaretz of Binyamina-Givat Ada who passed away recently and inspired us to analyse the centrality effects of train stations locations.

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VISUALIZING SPACE SYNTAX ANALYSES FOR DECISION MAKERS
Lessons from Israel

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ABSTRACT
Space syntax theory has been successfully incorporated into the urban planning field contributing to science-based urban design (Marcus et al., 2010; Karimi, 2012a; Lerman et al., 2014). While the theoretical foundations of space syntax require a thorough explanation (Hillier, 1996; Turner, 2007), its visualizations can be intuitive and serve as powerful tools in urban planning decisions.

To address the growing need of space syntax applicability this paper presents several visualization techniques employed in different planning projects to better communicate and discuss space syntax analyses. These techniques provide ways to clearly impart space syntax results to planners unfamiliar with this novel approach as well as to senior officials and other decision makers.

The case studies presented here are based in Israel and range from mixed-use brownfield development of a former airfield through a city centre revival plan to a municipality expecting massive growth on the fringe of a metropolitan area.

KEYWORDS
Geo-Visualization, Policy Making, Israel, Pedestrian Movement

1. INTRODUCTION
The space syntax discipline has come of age. Alongside recent improvements in GIS and the understanding of the complex nature of cities, space syntax is ready to take centre stage as one of the major fields that can improve decision making process in the face of growing challenges for cities all over the world (Karimi, 2016; Karimi, 2012b). This paper addresses the challenge of space syntax insemination which is central to this symposium (Heitor and Serra, 2016). This challenge refers to adding capabilities on top of space syntax analysis to increase its capacity and applicability. Specifically, this paper presents several geo-visualization methods used to better communicate space syntax analyses to decision makers in different planning context. The methods’ descriptions are then followed by a discussion on their impact on the planning processes and outcomes.

Space syntax analyses may at times, do not fit in current urban planning process. This has been elaborated on, especially in the North American context (Raford, 2010; Major, 2015). While there is a rather well-established transport planning discipline (c.f. McNally, 2007) and plenty of planning work done on land use and building volumes, space syntax approach do not follow either of these disciplines. Furthermore, current transport planning deals mainly with vehicular transportation, while space syntax has a major strength in non-motorized transport planning.
In addition, space syntax analyses can inform decisions on land use distribution and especially retail and location of major live-centres (Hillier, 1996; Hillier, 1999), yet under current planning practices these decisions are (usually) not taken following centrality and location systematic analyses. Moreover, space syntax derived insights may collide with conventional vehicular transport planning and land use allocation decisions, putting barriers to the introduction and use of space syntax in the planning process.

Recent computational advances have made space syntax ready to hit the mainstream with relative ease compared to the past. The open nature of Depthmap alongside the QGIS space syntax toolkit (Varoudis, 2012; Gil et al., 2015) make it easy to export space syntax results in various ways and use the GIS capabilities to build new visualization techniques. These techniques can be easily shared and improved, possibly leading to a library of visualization techniques available for different contexts. Furthermore, the capacity of Depthmap to handle large scale data as demonstrated by recent studies (Serra and Pinho, 2013; Serra et al., 2015) makes space syntax ready to tackle a larger set of planning decisions.

The rest of this paper is organized in the following way: the next section presents several visualization techniques applied in actual planning projects done in different urban contexts in Israel. The section afterwards discusses the impact of space syntax in policy making based on the projects presented earlier and the final section concludes with several suggestions for making space syntax a common planning aid with an expanded visual language.

2. VISUALIZATION TECHNIQUES AND CASE STUDIES

Three visualization techniques are presented in this chapter. Each technique is accompanied by an example from an actual planning project it was used at. The projects themselves are long-term in their nature and involve a myriad of planners, architects and consultants as well as decision makers at different levels. The three projects are taken from different municipalities, which are all part of the growing Tel Aviv Metropolitan Area: The city of Tel Aviv itself, the city of Rishon Letzion and the municipality of Binyamina. In the city of Tel Aviv space syntax analysis was applied in the planning of a new mixed-use quarter on brownfield land; in Rishon Letzion it was used in an urban regeneration plan; and in Binyamina it was applied in assessing new proposed regional roads necessity.

2.1 SPATIAL POTENTIAL IDENTIFICATION – TEL AVIV, DOV AIRFIELD PLAN

The visualization technique shown here uses space syntax analysis in order to identify a possible urban core inside a proposed project. This identification helps in recommending specific locations (i.e., street segments and intersections) where further planning considerations may be needed.

This specific projects deals with an existing airfield in the northern section of the city of Tel Aviv. As the airfield prepares to be shut down the land is ready for an urban development in an area just to the north of the intensive city core. Since the proposed project will become concrete only in the future there was a need for to identify the most significant new streets and intersections inside the project boundaries. An important street is a street that has a relatively high spatial potential compared to other streets inside the project, while an important intersection is an intersection where important streets meet. For the specific analysis in this case an axial map of the city of Tel Aviv was used in order to evaluate the spatial potential of the axial lines that are completely inside the project or cross its boundaries. Each of these axial lines was graded according to its spatial potential using a single measure going up from zero (least spatial potential) to five (highest spatial potential).

To quantify the spatial potential, several space syntax axial measures were used based on the literature regarding correlations between pedestrian movement volume and space syntax measures. These measures were: Global Integration, Local Integration (with $r=3$), Global Choice, Local Choice (with $r=3$) and Connectivity (for relevant literature please see: (Hillier et al., 1993; Baran et al., 2008; Lerman and Omer, 2013; Lee and Seo, 2013; Özer and Kubat, 2014)).
Specifically, this was done in the following way: initially all lines were given the value of zero as their spatial potential value. A point was added for the spatial potential value for each line that had a relatively high value in one of the five axial measures (in this specific example for the top ten percent values for each axial measure). Thus, each time an axial line had a specific space syntax measure valued at the top ten percent (among all lines inside the project), a point was added to its spatial potential value. Hence, an axial line that had relatively high values in all of the five measures got the maximum five points, while a line that had a high value only in a single measure got only one point. An axial line that did not appear in any of the top ten percent of the specified measures got a value of zero as its spatial potential. A short Python script, which does this calculation, available for QGIS, can be found online. This technique allows for a single map to reflect the spatial importance of all the axial lines inside the project area.

Overall, the Dov Airfield project consists of 121 axial lines (including lines that are fully or partially inside the project area). Figure 1 shows the Dov Airfield addition to the axial map of Tel Aviv. Presented in this map is the value of local integration ($r=3$). Table 1 presents the analysis of the axial lines according to this technique. As can be seen in Table 1, less than twenty percent of the axial lines have a spatial potential value which is greater than zero. This means that most of the axial lines do not exhibit relative high values at even a single measure. Out of the axial lines that do have a spatial potential value greater than zero (twenty one lines in all) a third have the maximum value of five (seven axial lines), meaning that they are the part of the top ten percent in each of the five axial indices mentioned previously.

A map which visualizes the application of this technique for Dov Airfield is shown in Figure 2. Presenting this map to decision makers enabled focusing further efforts on the urban design of intersections where two important axial lines meet (where each line had high spatial potential). This technique proved valuable in highlighting the most important streets and intersections in this project, where improvements to the public realm would have the highest influence and where complex transport planning decisions are needed to be made.
Table 1 - Axial lines values according to the spatial potential technique in Dov Airfield project.

<table>
<thead>
<tr>
<th>Value</th>
<th>No. of Axial Lines</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value of 5 (max)</td>
<td>7</td>
<td>5.79%</td>
</tr>
<tr>
<td>Value of 4</td>
<td>2</td>
<td>1.65%</td>
</tr>
<tr>
<td>Value of 3</td>
<td>2</td>
<td>1.65%</td>
</tr>
<tr>
<td>Value of 2</td>
<td>3</td>
<td>2.48%</td>
</tr>
<tr>
<td>Value of 1</td>
<td>7</td>
<td>5.79%</td>
</tr>
<tr>
<td>Value of 0 (min)</td>
<td>100</td>
<td>82.64%</td>
</tr>
<tr>
<td>All</td>
<td>121</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Figure 2 - Application of ‘spatial potential identification’ for the Dov Airfield project. The white circles mark the intersections with the highest spatial potential inside the project.
2.2 HEAD/TAIL PEDESTRIAN MOVEMENT VISUALIZATION – RISHON LETZION URBAN REGENERATION PLAN

The visualization technique shown here applies space syntax analyses to emphasize the pedestrian movement core of an existing urban centre based on an empirically calibrated pedestrian movement model. This visualization provides a clear map of the street segments where high pedestrian volume is expected and where the potential for urban revitalization is at its highest. The demonstrated project itself deals with urban revival and intensification of the centre of the city of Rishon Letzion. The project encompasses 162 hectares where currently there are 42,000 inhabitants. The city aims to intensify its centre with additional 130,000 square meters for offices and commerce as well as additional 5,000 housing units.

In order for the regeneration plan to take place, a multi-modal transportation plan was conceived, which enables central streets to serve their role as urban places and carry different kinds of traffic with efficiency and minimal friction among different road users. As part of this transportation plan space syntax analysis was used to create a pedestrian movement model (as previously done in other cases such as: Lerman et al., 2014). This model assesses the expected pedestrian movement volume for each road segment. The pedestrian movement model was used as a reference for city regeneration actions such as streets improvements, allocations of building rights and land use changes.

To allow for all stakeholders to easily relate to the pedestrian movement model a clear and simple map had to be provided. For this a straightforward visualization based on head/tail breaks proposed by Jiang (2013) was used. This algorithm breaks a heavy-tailed distribution in a deterministic fashion and captures the underlying hierarchy of the data. This is done by partitioning all the data values around the mean into two parts (head and tail) and continuing the process iteratively for the head values (above the mean) until the remaining head part do not exhibit a heavy-tailed distribution. Since pedestrian movement is not distributed evenly and many streets carry low volume of movement compared to the few that carry high volume of movement (Jiang, 2009), the head/tail breaks provide a fitting categorization for visualization of this movement distribution.

First, a pedestrian movement survey took place at 75 points using the gate count method on a sunny spring weekday. The survey was conducted for eight hours (From 10 AM till 1 PM and from 3 PM till 8 PM) in which for every hour ten minutes were observed at each survey point. The pedestrian survey itself also exhibited a heavy-tailed distribution with a low number of survey points having high volume of pedestrian movement and most survey points having relatively low volumes of pedestrian movement.

Thus, the 75 survey points were divided into the following three categories (shown in Figure 3):

1. High pedestrian movement volume (over 548 pedestrians per hour, on average) — 8 points which account for 11% of the survey.
2. Medium pedestrian movement volume (less than 548, but more than 240 pedestrians per hour, on average) — 15 points which account for 20% of the survey.
3. Low pedestrian movement volume (less than 240 pedestrians per hour, on average) — 52 points which account for 69% of the survey.

Out of the empirical survey a pedestrian movement model was created using statistical correlations in a similar fashion to other studies (Raford and Ragland, 2006; Lerman et al., 2014). The movement model itself reflects the nature of urban movement, with a high number of road segments carrying relatively low movement volumes and a low number of road segments who are subject to high movement volumes (Jiang, 2009). Therefore, the head/tail breaks algorithm (Jiang, 2013) was used to visualize the survey results.
The city centre itself comprises 1,280 road segments, which were divided into the following categories (shown in Figure 4a):

1. High volume of pedestrian movement expected (over 300 pedestrians per hour on average) – 97 segments which account for 7.6% of the city centre.

2. Medium volume of pedestrian movement expected (less than 300 and over 121 pedestrians per hour on average) – 200 segments which account for 15.6% of the city centre.

3. Low volume of pedestrian movement expected (Less than 121 pedestrians per hour on average) – 983 segments which account for 76.8% of the city centre.

Figure 4 shows the pedestrian movement volume model visualization under the head/tail breaks (Figure 4a) and under the standard space syntax colour scheme (Figure 4b). Finally, in order to present a clear and comprehensive model map which can be used easily by policymakers a manual cleaning process took place for which the results are shown in Figure 5. This refinement process removed isolated segments and added others to create a continuous and coherent network map. This map contains the city centre road network divided into the most important pedestrian core network segments, the secondary pedestrian road network and the background road network. The pedestrian core network segments are where most of the "tough" planning decisions are needed and where public space improvements carry the most benefits. The map shown in Figure 5 is not the correct model map, yet for practical decision making is makes more sense than the map in Figure 4a. This map can serve as reference point for different stakeholders since the segments in it are continuous, and fit the infrastructural decisions that this map can be used for (for a discussion on the benefits of clear and simple models in policymaking see: Givoni et al., 2016).
VISUALIZING SPACE SYNTAX ANALYSES FOR DECISION MAKERS
Lessons from Israel

Figure 4 - Pedestrian movement volume model for Rishon Letzion Centre: (a) shows the model after visualizing according to head/tail breaks; (b) shows the model visualization using classic space syntax colour scheme.

Figure 5 - The pedestrian movement model results provided for decision makers after a manual clean-up intended to produce a more coherent map.
In this case, the space syntax analysis contributed to changing the way the decision makers and the rest of the planning team looked at the regeneration project in its entirety. Space syntax analysis helped create a plan that directs the intensification and improvements to the most important street segments in the city centre (in terms of pedestrian movement and vitality) by focusing efforts on public space and road sections changes along these segments.

2.3 CHOICE IMPACT FOR ASSESSMENT – BINYAMINA OUTLINE PLAN

The visualization technique shown here applies space syntax analyses to assess vehicular movement patterns and to evaluate possible changes due to the introduction of new regional roads.

The demonstrated project in this instance deals with vehicular transportation planning in a growing community. The municipality of Binyamina is located at the fringe of Tel Aviv Metropolitan Area and is expecting significant growth in the coming years. The size of the municipality is 2,400 hectares with 15,000 inhabitants, expecting to grow to about 30,000 by 2040. In line with the expected growth there are plans to add new regional roads. Besides the conventional transportation assessments using the four-step model (McNally, 2007), space syntax analysis was used to assess the new roads relevance and impact on vehicular flow changes. Space syntax analyses afforded a quick way to assess the impact of new regional roads on existing roads inside and outside the municipality. The current vehicular conventional models use traffic analysis zones and do not have the resolution to analyse specific urban segments that may act as critical movement sections.

In order to assess potential vehicular flows, this analysis focused on angular choice measures (Turner, 2007) as the choice measure reflects the through-movement potential of a given segment in the network. In addition, the analysis was applied at different radii reflecting different regimes for movements that occur at different distances – from medium vehicular distances (5 km) to longer trips (20 km and beyond).

The visualization technique presented here shows the relative impact on angular choice values following proposed changes to the road network. Specifically, it was done separately for potential shorter trips (5 km up to 10 km) and potential longer trips (20 km up to 75 km). This technique focuses on the relative change in the choice value on a given road segment and not the absolute choice values. The specific steps used for this visualization are describes below:

1. Analyse the existing and planned road network at different radii. In this case we considered ranges of 5-10 km for local trips and 20-75 km for longer trips.

2. Normalise Choice variables by dividing at the max value for each radii resulting in values between zero and one.

3. Divide the planned network’s normalised choice values by the existing network’s values for each radius under consideration, for all overlapping segments. Values that are higher than one represent choice value increase (signifying probable higher motorized demand for the road segment under future conditions), while values that are lower than one represent choice value decrease (signifying probable lower motorized demand for the road segment under future conditions).

4. Visualize the choice increases and decreases in the clearest way possible. In the case presented here we used equal breaks separately for the increased and decreased value and then superimposed them together.

This method has several drawbacks such as that it does not take the size and speed of the roads into account. If the trip distribution is known (for example how many trips are shorter than 20 km and how many are longer than 20 km), the super-imposed map can be tuned to reflect this actual distribution. Preliminary results show merit for using the choice variable as a proxy for vehicular movement at different radii but further work needs to be carried out.

Figures 6 and 7 present the superposition of choice impact analysis at different radii. Figure 6 shows this analysis for long radii of between 20 km and 75 km (intended to capture longer trips).
made out of specific analysis at radii 20 km, 40 km and 75 km. This figure shows that a new road (dashed green line) would increase the number of long trips using the eastern highway (Highway 6), while lowering the number of long trips using the western highway (Highway 4). Figure 7 shows the same for shorter radii of between 5 km and 10 km (intended to capture local trips) made out of specific analysis at radii of 5 km, 7.5 km and 10 km. This figure shows that the proposed new road would enlarge the number of short trips using road 653.

Figure 6 - Choice impact analysis for longer distances (20 km up to 75 km) for Binyamina regional roads.
Figure 7 - Choice impact analysis for shorter distances (5 km up to 10 km) for Binyamina regional roads.
The analysis applied in this project proved especially effective both in understanding whether the new roads may cause current roads to be bypassed (i.e. actually changing congestion patterns) and to understand the combined impact of the new roads together.

3. RESULTS – IMPLICATIONS FOR POLICY MAKING

In all three cases described above the major impact of using space syntax as part of the planning process was to focus the planners’ attention on the importance of the road network structure and its impact on the other planning decisions needed to be made (changes to street sections, land use distribution, multi-modal transportation and so forth).

Except for the third example (Binyamina) where the decisions were already centred on possible changes to the regional road network, the other two examples helped to change significant parts of the principal discussions to the road network structure itself. Furthermore, this new focus offered the ability to analyse possible changes to the road networks and their implications regarding transportation, land use and so forth.

As far as these particular projects show, the planning community (at least in Israel) is ready to embrace network planning as part of the planning process itself. It can be considered as a step toward making the urban planning profession an evidence-based one (Marshall, 2012). Applying space syntax as part of the planning process adds an analytical component, which helps in focusing the planners’ attention on the vital importance of the road network structure.

4. CONCLUSIONS

To summarize, in the studies presented in this paper, the attention to the road network’s impact on urban dynamics helped planning teams get back to the traditional way of urban planning. That is to say that road network planning (connectivity and right of way allocation) comes before decisions on land uses, buildings and interiors are made and not the other way around.

Several limitations in the work presented here include the fact that these visualization techniques are experimental in their nature and have not been developed through consistent usage. The different visualization techniques themselves were used in a somewhat arbitrary way. Further work is needed to assess the visualization techniques proposed here in a systematic way.

Another recurrent challenge in the application of space syntax is the almost unavoidable friction with (conventional) traffic engineers. The current use of the four-step model (McNally, 2007) reigns supreme when discussing and predicting vehicular scenarios. Space syntax has not been used to a significant degree for vehicular transport planning, even though it seems to be of great potential (Pereira et al., 2012). Further research should assess space syntax accuracy versus that of the conventional transportation models and look to reduce the current friction between the two approaches. The possible application of space syntax in the most traditional transportation planning context may help spread it further and faster.

Finally, several other challenges come to mind when considering the potential of space syntax and the contribution of the space syntax community. A current state-of-the-art practice compendium may well be due. This proposed compendium should provide guidelines on best practice of space syntax with regards to transport planning, land use, urban regeneration and so forth. Another possible venue may be to create an open visualization scripts library which will enable consistent space syntax analyses in different kind of projects and contexts besides the Depthmap related visualizations.

Easy, fast, consistent and reproducible visualizations based on space syntax analyses would open the way for space syntax to be in a considerable greater use than is currently done. Also, at times, planning projects require adhering to a strict timeline that is rather short and insufficient for a rigorous and thorough research. This is another point where consistent visualization tools can help in reducing the amount of time and effort needed to communicate space syntax results. Right now, space syntax is more often than not used for the most complex of projects (Marcus et al., 2010), where traditional design tools have significant limitations. It can and should be
used much more frequently in planning decisions in order to facilitate the move to evidence-based design (Marshall, 2012; Karimi, 2012a).

In conclusion, this paper presents additional capacities and capabilities for space syntax usage in urban planning in different contexts. Overcoming the insemination challenge (Heitor and Serra, 2016) would require further work, yet the simplicity and elegance of space syntax shows promise for a highly useful method for urban planning.

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NOTES

Please see: https://github.com/ylerman/Top20

\(^2\) Applying a stepwise regression resulted in an R-square of 0.69 compared to the observed pedestrian movement volume (with p<0.01). The model needed only two variables – an angular integration with radius of 1,000 m (which had a correlation coefficient of 0.59 to observed pedestrian movement volume) and commercial fronts distribution variable (which has a value of 0 for no commerce, 1 for partial commerce and 2 for two-sided commercial street segments).

For further details on statistical correlations and movement model please see: Lerman et al., 2014. The model equation itself for the log value of hourly pedestrian movement model is as follows:

\[
2.755913 + 0.009 \times \text{angular integration at 1,000 m radius} + 0.514 \times \text{commercial fronts}
\]

\(^3\) Since the discussion of future changes to the road network involves sensitive propositions which are still being deliberated by the cities’ officials themselves we are unable to share them in this paper. However, we have used the same techniques described in this paper to evaluate and visualise the impact of hypothetical changes to the road network in each of the cases.
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A SYNTACTIC COMPARATIVE RESEARCH ON THE OLD AND NEW AXES OF GUANGZHOU, CHINA

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ABSTRACT
While the urban morphology of Guangzhou is characterized by two urban axes formulated at different historical periods, there is a need for research to review their relationship with the rest of the city and evaluate their structural performance within the overall urban layout, notably when the urban fabric of Guangzhou has been increasingly criticized as fragmented and isolated in nature. In comparison with previous studies focusing more on their physical forms, visual aesthetics, transportation organization at a local scale, this study carries out a comparative analysis of the two axes in terms of their geometric characteristics, spatial permeability and ductility, topological accessibility by applying the methodology offered by space syntax. Through investigating their configurational properties and how they play a role in the overall urban structure, this study aims to identify some problems occurring in the process of urban development, in addition to providing valuable reference for future preservation and revitalization of the axial areas.

As a result, the study reveals that the old axis of Guangzhou demonstrates a better spatial permeability, higher topological accessibility and intelligibility at both local and global levels; by contrast, the new axis is featured as insufficient spatial permeability and displays an inferior controlling role in the overall urban layout owing to its relatively fragmented development pattern and inconsistent spatial logic with the rest of the city irrespective of the fact that it was built to be a new CBD of Guangzhou and even of the Pearl River Delta Region.

KEYWORDS
Urban axes, geometric characteristics, spatial permeability and ductility, topological accessibility.

1. INTRODUCTION
As an important element of urban design, the axis always functions as the main line of direction, motion, growth, or extension (Definition in Oxford Dictionary). In most circumstances, the line is implicit, serving as an organizing principle to which compositional elements are referred. Reviewing the history of human society, the axis plays an important role in the process of urban development. Hence, it comes as no surprise that numerous famous cities of the world, including Washington D.C., Paris, and Beijing, are characterized by their urban axes.

The building of axis somehow originated from human’s respect to the laws of nature, which are always represented as the aesthetic of symmetry, regularity and order. Therefore, in the
original built environment, building layouts were inclined to face north-south, reflecting people’s psychological worship to the Sun, as well as meeting the demand of getting enough sunlight in their daily lives. With the development of society, axes began to bear upon more functions, and gradually evolved as a device to establish certain social orders and to symbolize the power of control by emphasizing specific direction, spatial hierarchy and sequence; while in modern society, being influenced by modernist planning principles, the axis has become a design method to organize various functions, spaces, traffic and landscape, promoting urban activities and stimulating economic development (Wang, 2003). Acting as a skeleton of urban spatial structure, axes can epitomize the historical process of development or cultural tradition of particular cities. Also, urban axes can help build up a city’s image by providing iconic public spaces for visitors and local citizens. In this sense, to understand the characteristics of urban axis and its relationship to the rest of the city is important for both research and practical purpose.

Owing to the significance of axes, there have been a number of authors who paid their attention to the development of axes and their possible implications for functions. For example, Li (2003), Zheng and Li (2008) studied the axis of Beijing regarding its origins, form and relationship with the whole city and finally identified some problems occurring during the process of urban development. Similarly, Tang et al. (2000) investigated the new axis of Guangzhou from three aspects: its development pattern, planning concept and design principles. By contrast, some other authors analysed urban axes mainly based on their values in historical and cultural preservation and revitalization (Duan, 2003; Zhao & Cao, 2007; Yang, 2007). Indeed, these studies are insightful and can provide valuable references for the studies in other cities. However, it is noticeable that most of them emphasized the surface characteristics of the axes themselves, lacking of attention to their underlying structure and their relation to the rest of the city by embedding them into the urban system as a whole. Also, from previous studies, it is still unclear if and how the geometrical differences of various axes have brought some implications for social aspects.

The necessity of investigating axes systematically is also supported by the fact that, with few exceptions, cities always came into being through a process of growth and change over a long period of time so that they display neither spatial nor functional simplicity (Hillier, 1996). Morphologically, this process has resulted in a continuous and interconnected spatial system through the organization of elements such as buildings. Within this system, morphological elements including axes are not homogenous and isometric, but unique and differentiated from each other with reference to the whole (Hillier & Hanson, 1984). Based on the research purpose as set, this study then chooses Guangzhou, the largest city in the south of China as the study case. Through carrying out a configurational analysis by using the theory and methods provided by space syntax, the structural and functional performance of the two axes of Guangzhou are examined and compared both systematically and precisely.

2. THE URBAN AXES OF GUANGZHOU

Having the history of over 2000 years, the urban development of Guangzhou has aroused the interests of a number of authors. Owing to its natural environment and special historical background, Guangzhou has established a series of urban axes, which comprises of the Pearl River as a landscape axis running from west to east and three north-south oriented axes formulated in different periods of time, namely the ancient axis, the modern axis and the contemporary axis. Since the shape of the ancient axis is implicit, it has been seldom discussed among researchers. Eventually, this study mainly focuses on the properties of two axes: the modern (also named as the old axis) and the contemporary (the new axis) axes for further study purpose.

The old axis is located in Yuexiu District and is about 0.9 km long. Starting from the Yuexiu Mountain, the old axis is mainly composed of Zhongshan Memorial Hall, City Government, the People’s Park, Qiyi Road and Haizhu Square from north to south, ending by the Pearl River (Fig. 1). Visually, the plan layout of the old axis is relatively orderly and regular, defined by a variety of important buildings. Also, the spatial pattern of the area appears to be more continuous, leading to a continuous streetscape within the district.
By contrast, the new axis of Guangzhou with a total length of 4km starts from Guangzhou East Railway Station, followed by East Station Square, CITIC Plaza, Sports Centre, Hongcheng Commercial Plaza, Liuyun Residential Area, and Zhujiang New City form north to south and finally ending with the Pearl River (Fig. 1). In comparison with the old one, the new axis features on large-scale development patterns, largely manifesting the top-down urban planning principles.
3. COMPARISON OF SURFACE PROPERTIES OF TWO AXES

Prior to the configurational analysis, the surface characteristics of the two axes are analysed. First, the traditional axis is about 0.9km long and 0.24 km in width. On average, its block size is about 200 * 200, but the block occupied by the People's Park is 200 * 320. In the old axis area, the urban fabric tends to be diverse and compact, accommodating the developments at different scales. For example, the northern part is mainly occupied by Government buildings, resulting in larger-scale street blocks, while to the south of Zhongshan Road, it mainly accommodates a variety of small-scale commercial and residential developments.

By contrast, situating in the central area of the Tianhe District, the new axis of Guangzhou is about 3-4km long and 0.7km wide. Being organized in a strict symmetry manner and aligned with numerous landmark buildings, the new axis is considered as a reflection of the centralized planning principles. Inside this area, the average block size is 400*400, with the Tianhe Sports Complex being 600*800, three times larger than the People's Park. Also revealed by the figure, the urban fabric of new axis exhibits a relatively fragmented pattern, lacking of continuity and coherence as displayed by the old one.

As far as land use pattern is concerned, significant differences can be found between the two axes. While the old one, where the ancient city of Guangzhou was located, accommodates a considerable number of historical heritages and traditional culture resources, the new axis mainly comprises of contemporary commercial and office buildings with the aim to form the new CBD of Guangzhou even of the Pearl River Delta Region.

When concerning the street network and its density, it is found that the street network density of the old axis is 0.028m, higher than the new axis of 0.024m, implying that the network of old axis area can offer a higher level of accessibility than the new one.

From above geometrical analysis, some problems can be raised:

- As a typical development model of Guangzhou, both old and new axes have taken on various roles and functions. However, as an important metropolis of China, Guangzhou has decided to adopt a dispersed and multi-centre model for its future spatial development, which seems self-contradictory to the establishing of city axes, thus may raise continuous debates in the society.

- Historically, the old axis was located in the geographical centre of Guangzhou, thus accumulating rich historical heritages and cultural resources in surrounding areas. Nowadays, its geographical advantage has been weakened by the development of the new axis, but as part of the city memory and symbolizing the local tradition and culture, its meaning is ever-lasting. Therefore, it would encounter the issue of renewal and preservation in the future.

- From the beginning, there is no geographical significance for the building of the new axis irrespective of the large-scale development pattern initiated and operated by the municipal government. As mentioned, it is somehow self-contradictory notably when the dispersed and multi-centre development pattern have been adopted over the past several decades. In this sense, it is fair to infer that the new axis will face the issue of optimization and improvement in order to itself better into the overall urban structure. In light of these issues, it is imperative for research to achieve a precise understanding of the spatial structure of the two axes and their current performance.

4. CONFIGURATIONAL ANALYSIS OF TWO AXES

The configuration analysis in this section is carried out based on the segment analysis provided by space syntax. Two major configurational properties of the urban system are to be measured, they are integration and choice, which will be devised to identify to-movement and through-movement potential respectively. More specifically, the comparative analysis of two axes is focused on several morphological characteristics, including the distribution of integration and choice values, the accessibility and ductility of pan-axis area, the intelligibility and synergy.
Considering the urban characteristics of the Guangzhou city, three metric radius are selected to constrain the analysis, they are 800m, 3000m and n. As a result, a number of graphs are generated through Depth X.

Figure 2 - Distribution of the 10% (above) and 20% integration of r800m

Figure 3 - Distribution of the 10% (above) and 20% integration of r3000m
4.1 RELATION TO THE INTEGRATION CORE

When concerning the R800m integration of the whole city (Fig. 2), the analysis shows that the 10% most integrated segments are distributed as patches, mainly concentrated in the historical areas- the Liwan and Yuexiu District, with a small percentage of segments distributing in Tianhe District. Also, it is found that the south section of the old axis belongs to the 10% syntactic core, implying that these streets are the most accessible places at the local level. When the percentage of the core is expanded to 20%, more segment lines of the old axis become part of the core; while in the new axis area, more lines, such as Guangzhou Avenue, Liede Road are included, forming an incomplete grid pattern.

When the metric radius is set as 3000m (Fig. 3), representing the mesoscale of the urban structure, the analysis shows that the 10% most integrated segments tend to form two distinct clusters. One is featured as dense and deformed grid pattern located in the historical areas (the Liwan and Yuexiu District), with the other appearing as big and regular grids concentrated in the Tianhe District. In the historical areas, the core has slightly shifted northward and is characterized by long street segments rather by short and dense lines as displayed by the R800 integration. Also revealed by the figure 3, the old axis tends to be completely embedded within the syntactic core, demonstrating a strong to-movement potential and good gathering functions; while in the new axis area, the lines with high integration value are mainly located along Tianhe Road and Huangpu Road, both of which are running from west to east, as well as along Guangzhou Avenue, Tiyu Xi Road, Linhe Road and Tianhe east Road running from north to south. When the study investigates the 20% syntactic core, more street segments are included and the connection between two clusters becomes stronger.

According to space syntax, the integration of radius n (Fig. 4) represents the foreground structure of the city, offering traffic potential for vehicles. As a result, the analysis shows that the integration of Rn is characterized by a bidirectional grid pattern. In the historical districts, the west-east roads function as skeleton, being connected by numerous north-south streets as...
branches. However, to the east of Guangzhou Avenue, the most integrated lines tend to form a complete and uniform grid pattern, far extending to its east.

From the above analysis, it may be summarize:

- With the increase of metric radius, the distribution of segments with high integration values changes from a number of scattered patches into a complete grid pattern, covering most of the major roads.
- With the increase of metric radius, an increasing number of lines in the old axis belong to the syntactic core. At both the community scale and the global scale, the old axis embodies a better traffic potential of arrival, theoretically having a good capability to gather social activities. At the mesoscale such as radius 3000m, its spatial structure performs the best, implying that it is likely to be the most accessible place in terms of pedestrian and light traffic movements.
- The accessibility of the new axis is not strong at the local and community levels, indicating that it cannot gather pedestrian movement as the old axis. However, with the increase of metric radius, most of the major roads of the area demonstrate high integration values, subsequently formulating a complete network to support vehicular traffic. Another characteristics revealed by the analysis is that except for the major roads, the integration value of other streets did not show significant changes no matter what metric radius is selected, implying that the its background structure is relatively lacking in the new axis area.

4.2 RELATION TO THE CHOICE DISTRIBUTION

Choice is an expression of through-movement potential of the street network in space syntax. The smaller the metric radius is selected, the closer the choice is to the pedestrian behaviour, whereas the bigger radius is more associated to the movement of vehicles. Consequently, the analysis of radius 800m(Fig.5) shows that the southern part of the old axis exhibits a good through-movement potential, implying that the area around Qiyi Road theoretically has high potential to gather social activities; while in the new axis, only Tianhe Road and Huangpu Road display high choice values.
When it comes to the radius of 3000m and n(Fig.6), the corresponding figures illustrate that the segments with high choice values tend to cover most of the major roads of the city, implying that the road network of Guangzhou was stratified more for the movement of vehicles. Unsurprisingly, as far as the two urban axes are concerned, most of their major roads are characterized by high choice values.

4.3 COMPARISON OF NACH, NAIN, INTELLIGIBILITY AND SYNERGY OF THE TWO AXES

The analysis in this section shows that the average NACH (the normalized choice value) of the old axis is much higher than the new one. At the radius of 3000m, the NACH of the old axis is the highest (Fig. 7). As to NAIN, the normalized integration, the average value of the traditional axis is slightly higher than the new axis. Another finding of the analysis is that the average NAIN value of the old axis increases with the metric radius, but no significant changes can be found for its maximum values.

When comparing the intelligibility of the two axes (Fig. 8), the figure shows that the old axis is more intelligible than the new one even though the value is not high, implying that its spatial structure is more legible for pedestrians or vehicles moving around. Yet a bit surprisingly, as far as synergy is concerned, the new axis demonstrates a higher synergy value, implying that it has better local and global relationship, and subsequently people are easy to infer the global structure from the local immediate spatial properties. This may be explained by previous finding that the background structure is relatively simple and lacking in the new axis areas, resulting in insignificant differences revealed between local and global structures.
4.4 ANGULAR STEP DEPTH ANALYSIS

Structurally, the axis is part of the urban spatial system, and it should have an inherent connection with the other parts of the city; therefore, the analysis should not be constrained to the axis itself. To investigate their embedded level within the whole urban layout, this paper also investigates their angular depth map of 3 steps (named as pan-axis area in this paper).

As to the old pan-axis, the figure 9 shows that three step depth distributes evenly, with good connections to the surrounding areas. Also, its configuration shows a good continuity because there is no abrupt change to be found when the step depth is decreasing. It is worth mentioning that part of the new axis is also located within the old pan-axis, proving that the old axis has better structural ductility, theoretically being able to function as an authentic centre of the city.

By contrast, the depth of the new pan-axis extends well to its east edge, while to the west, the lines of two steps are mainly concentrated on the east side of Guangzhou Avenue, implying that Guangzhou Avenue has become a barrier, limiting the extension of the new pan-axis to its west.
5. CONCLUSION

• The geometrical scale of the traditional axis is relatively small; however, it demonstrates a better structural performance from the configurational points of view. In particular, at both local and global levels, its accessibility and potential to accumulate to- and through-movements are stronger, reflecting its capability to gather social activities. Therefore, it is more likely to function as a morphological and functional centre in the overall layout of the city.

• In comparison with the new axis, the traditional axis has demonstrated better ductility together with good connections with the rest of the city in all directions. By contrast, the new axis displays better to- and through- movement potential mainly at the global level, indicating that its street network is planned more to support vehicular movement. Also, the analysis indicates that the background structure, which is more related to pedestrian movement, is lacking inside the new axis area.

• Since the old axis has considerable structural advantages, the issue of its preservation and revitalization should be carefully considered in the future spatial redevelopment. By contrast, the foreground network structure of the new axis has functioned intensively, but the lacking of background structure and poor connection with the west of the city should be improved so that it can function as the authentic centre of the whole city.

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STUDY OF PUBLIC SPACES AND RECREATION AREAS IN THE CITY OF URUAÇU (BRAZIL)

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ABSTRACT

The demand for public leisure spaces has grown considerably in recent years, since daily routine at work and in transit make people look for places to rest. However, in the vast majority of cases, these spaces do not offer appropriate conditions of use, such as irregular sidewalks and debris, a problem directly related to the comfort and accessibility of passers-by; Another obstacle is caused by bad lighting in the roads, affecting the safety of the population. This is due to the lack of maintenance on the part of the residents and the public power. Based on the data collected through the Portal Method (Grajewski and Vaughan, 2001 apud Barros, 2013) in a specific region of the city of Uruaçu-Goiás, this article analyzes the flow of pedestrians and vehicles, a survey was made on the use and occupation of the land, and the number of entrance gates to the lots, in order to correlate the data to the subject in question. Thus it was found that vehicle traffic is substantially larger than that of pedestrians, and the public places do not offer accessibility conditions for all. As a consequence, people end up looking for entertainment in the urban centers that they could find near their home. In the study area there are no leisure facilities that provide safety and comfort. Making it necessary to have a space for people to expand their social contact and the environment.
KEYWORDS
Accessibility, Public Spaces, Recreation, Flow

1. INTRODUCTION

Some theories predict that after the Industrial Revolution, contemporary Western civilization starts to get into the culture of leisure, where the man goes to devote greater and better part of his energies to activities that enriches and stimulates pleasure (Santini, 2003). For Dumazedier (2000, p. 34), leisure consists of “a set of occupations to which the individual can surrender freely, whether to rest, to have fun, to recreate himself (...) or get rid of professional, family and social obligations”.

The research in question, examines the relationship of spatial configuration, referring to accessibility and the leisure area of the city of Uruaçu-Goias, specifically in the northwest area of downtown. Thus, an analysis based on the data collected via the Portal Method (Grajewski and Vaughan, 2001 apud Barros, 2013), investigating the flow of pedestrians and vehicles, in the region of study.

Thinking that several citizens work far from home, and do not want to go to their residence during free time (such as lunch), these spaces may come in handy for a brief rest, without any concern for safety. According to Amendment No. 26 of the São Paulo state government, in order for a new neighborhood to be approved, it should allocate a portion of the area to the public leisure spaces.

Considering the above, the research in question presents an analysis of the flow of automobiles and pedestrians in a certain region of the city of Uruaçu, being verified the importance and necessity of leisure, considering that these spaces may come in handy for a brief rest, without that there is concern about safety and with that bringing a visual comfort to the population.

2. DATASETS AND METHODS

The methodology adopted to analyze the problems related to accessibility in the municipality of Uruaçu, more specifically in the northwest zone of the Centro district (Figure 1), can be divided into two stages: bibliographic review and information collection. In order to define the relevant issues, this collection was directed to them, consisting of: counting of pedestrians and vehicles by the Portal Method (Grajewski and Vaughan, 2001 apud Barros, 2013), count of the number of gates, indication of the use and occupation of the ground and identify accessibility issues pertaining to the region.

The pedestrians and vehicles count was performed 8 times in 4 different days of the week set to indicate a heterogeneous flow behavior during the middle (Monday to Friday) and the weekend (Saturday and Sunday). On each day, the count was done during the morning peak in the range from 7 o’clock am to 9 o’clock am and afternoon peak in the range of 5 o’clock p.m to 7 o’clock p.m.

3. RESULTS

Analyzing the region of study, there is the absence of public spaces. The few found in this scope, are in precarious conditions, thus not allowing the permanence of the population in these places.

When one observes the map referring to the use and occupation of the soil (Figure 1), there is a predominantly residential area. Table 1 shows a survey of the flow between cars and pedestrians, noting that vehicle traffic is more intense in this region.
Figure 1 - Land use map of the centre of Uruaçu.

<table>
<thead>
<tr>
<th>Streets</th>
<th>Saturday and Sunday (12/12/2015 and 12/12/2015)</th>
<th>Monday and Tuesday (12/14/2015 and 12/15/2015)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vehicles</td>
<td>Pedestrian</td>
</tr>
<tr>
<td>Pedro Ludovico</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td>Leopoldo de Bulhões</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>Porto Nacional</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Isabel Fernandes</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Dona Candida</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Travessa Machombombo</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Manuel Ribeiro Sobrinho</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>Travessa Brasilia</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Oldrado Silva Rocha</td>
<td>30</td>
<td>5</td>
</tr>
<tr>
<td>Quintino Bucaiuva</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Iracema do Norte</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Benedito Almeida Campos</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Pio I</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Rio Verde</td>
<td>22</td>
<td>10</td>
</tr>
<tr>
<td>Alvino Mendes da Silva</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1 - Flow number of vehicles and people.
In order to promote socialization among individuals and to provide the surrounding population of the research region with safe and easily accessible recreation sites, an alternative would be to create public spaces and improve those which already exist. Also developing the commerce of the region and thereby increasing the movement of pedestrians.

According to Cabezas (2013), the comfort of a public space is acquired when it reaches its maximum utilization, coinciding simultaneously with a set of ideal conditions, determined by factors such as: thermal conditioners, urban scale, occupation of public space, perception of safety, acoustic conditions, air quality, ergonomics, etc.

Since the creation of a new public space, such as a park or a square, demands time and money, it is proposed to revitalize existing ones, in order to guarantee all the conditions for their maximum use, taking into consideration as ideal conditions of a leisure space.

Another point that must be analyzed more rigorously is accessibility, not only in public spaces, but also in the region as a whole. Accessibility does not refer only to people with physical needs, but the population in general. When considering the sidewalks as elements of transition between the private (residence, commerce) and the public (street), one can perceive a great amount of factors that make them unusable as spaces of leisure.

After observing the mobility of the municipality of Uruaçu, the great majority of the sidewalks do not correspond to the required by law, which is because the city was not planned. Therefore, the access to the sidewalks, when they exist, makes the pedestrians find it quite difficult, having to choose the traffic in the streets, next to the vehicles.

The owner of a property is responsible for building the sidewalk or promenade in front of his lot and should keep it in perfect state of conservation. Decree No. 5.296 / 04, regulates Laws No. 10488/00 and No. 10.098 / 00, which establish general norms and basic criteria for the promotion of the accessibility of persons with disabilities or with reduced mobility.

In this way, the use of sidewalks as living areas at strategic points, besides providing pleasurable moments and more health for citizens, could encourage the residents to a conscious measure to organize them according to the needs of the pedestrian.

After data collection took place from December 12th to 15th, 2015, it was possible to establish relationships that represent the number of people moving around in the course analyzed. The following are the values found:

The displacements by vehicle were more distributed between Pedro Ludovico Avenue, Leopoldo de Bulhões Street and Rio Verde Avenue. Among the pedestrians, Leopoldo de Bulhões Street presented a more salient value than the others.

The movement of pedestrians was homogeneous throughout the studied region as a whole, and Quintino Bocaiuva Street presented the highest percentage of pedestrians within an hour. On the other hand, the vehicles were in greater quantity in the Avenue Pedro Ludovico, followed by the Rio Verde Avenue, and the Benedito Almeida Campos Street.

At weekends there was an average displacement of 483 vehicles and 129 pedestrians per hour, while the weekly days were 924 vehicles and 144 pedestrians. What makes it more evident that the number of pedestrians has not undergone major changes in quantity on weekdays, only vehicles that practically double on weekdays.

Figure 2 shows the data obtained by counting gates available for the analyzed region totaling 631. Of this value, 10.7% is located on Oldrado Silva Rocha Street, previously observed as the second street with the largest flow of vehicles. Pedro Ludovico Avenue has a greater flow of vehicles, but only 6.8% of the gates observed. Among the pedestrians, there was no correlation between gates and displacements, since for each observed day, greater movements were registered in different places.
4. CONCLUSIONS

The article in question clearly outlines ways to solve the problems in the urban environment of the municipality of Uruaçu, more specifically in the central region. Based on the data obtained, a parallel can be made between the study variables and the living areas. Looking further, one notices that this is not a specific problem that is present only in the city of Uruaçu, but it is also a problem in most large urban centres.

The analysis of the centre of Uruaçu indicated several problems such as holes in the streets, garbage and debris on the sidewalks. Another major problem is the lack of security and trust of the people in the environment that they live and the streets that circulate every day, a dangerous need, and for many, a daily challenge.

The flow of pedestrians is more constant on the streets that have sidewalks with transition elements, and developing this mechanism is an attractive way to make public spaces, areas with greater vitality. In addition to making the routes safer for all people.
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SHIFTING PLACES AND COMMUNITY LIFE?
Comparing Morphology and Uses after a Community Reallocation from a Favela to a Housing Estate in Natal/RN, Brazil.

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ABSTRACT
The ampler research, of which this study is the initial phase, aims to investigate the effect exerted by morphological changes over the way space is used, guided by the notion that patterns of encounter are organized by the architecture of the settlement and their relation with the architecture of the city. This paper addresses, specifically and comparatively, the space morphology and uses of two settlements that are part of a reallocation process in Natal (Brazil): a slum – Favela do Maruim – and a housing estate – Residencial São Pedro – built to accommodate the inhabitants removed from the former settlement. Favela do Maruim, a community mainly engaged in the fishing trade, located besides the river Potengi – its raison d’être – dates from the 1940s. The 172 families that inhabited its 156 homes, are being transferred to the housing estate that comprises 200 flats (25 blocks), sited 700 meters away from their former community. The new settlement planned as a regular grid, was built in the context of a national housing programme, Minha Casa Minha Vida. As space may promote or hinder encounters, and believing that the day-to-day community life at open spaces was a vital part of the social life in Maruim, we investigate spatial attributes and relate them with uses in both settlements at three moments – when the residents were living in the Favela, the housing estate present situation (with building fences), and as planned by the architects – focusing the open spaces within and around their limits and their relationship with the global city. Axial and segment analysis characterized the insertion of each settlement in the city structure, at varying topological radii and metric distances, and their inner structures were examined through Visibility Graph Analysis. Although less orderly and integrated into the global urban tissue, the asymmetric and fragmented configuration of the favela irregular enclave defines a strong spatial hierarchy, which privileges certain convex open spaces as points of confluence for pedestrian routes and open-door activities. Not surprisingly, these spaces also show strong private/public interfaces. A different spatial logic guides the modern housing estate Residencial São Pedro, where a homogeneous order pulverizes uses. The study so far, therefore, indicates that, in this case, the morphological change can alter modes of use and encounter, and seems to inhibit community life.
KEYWORDS
Spatial Configuration; Reallocation; Housing Estate; Slum; Favela do Maruim.

1. INTRODUCTION

This paper is part of an ampler research that aims to investigate the effect exerted by morphological changes over the way space is used, guided by the notion that patterns of encounter are organized by the architecture of the settlement and their relationship with the architecture of the city. Architecture is viewed as a composition of masses (buildings, equipment, walls, fences) and voids (streets, doors, passages, permeable open spaces) that creates a field of possibilities and restrictions for encounters of different groups – inhabitants and strangers – contributing to social processes and dynamics believed to be the basis of social life.

By focusing on the reallocation of a community of favela residents to a housing estate in Natal/RN, Brazil, this research phase attempts to understand the extent to which the space structure in the previously inhabited settlement differs from the one – designed under government guidelines – where most residents now live, and if changes in the patterns of encounter amongst dwellers can be observed. This paper advances some preliminary observations only (based on initiatory visits and photographic records), since the systematic exploration of possible relations concerning uses and attributes of the physical milieu is the essence of the following research phase.

“Favela do Maruim” is located besides the river Potengi, next to the city’s harbour, sited in its broad estuary; it is an organically self-built informal settlement, developed by individual actions throughout decades. Before removal, 172 families resided in its 156 dwellings of varying sizes, mostly in insanitary conditions. The reallocation has been proposed by various administrations for a long time and gained strength as part of the harbour expansion plan early this century. In 2013, Natal’s municipality initiated the construction of a housing estate near the favela aiming to remove the community to a site within their own neighbourhood. The “Residencial São Pedro” was funded by the federal housing programme “Minha Casa Minha Vida” and was ready for habitation in July 2016. The estate plan, likewise numerous other such development, is an orthogonal grid, flanked by four-floor blocks of flats, totalizing 200 units distributed over 25 buildings. As of April 2017, the reallocation is still in course.

Given that architectural form, in its broader sense, outlines the history and culture of the people who produced it, architecture is both the expression and embodiment of social needs and values. Brazilian cities are dramatically efficient in generating unequal societies that find expression in urban patterns of socio-spatial segregation (Villaça, 2001; Ferreira, 2014; Carmo, 2014). Favelas were born within a context of urban, economic, political and social discontinuity. They seem disorderly from a bird’s-eye view (Hanson, 1989), because their formal properties are not those associated with the idea of social order. However, favelas are habitats of survival simplified at its extreme; without the help of planners and architects, they reveal the logic of a situation in which people are not given options to choose from. Favelas are assembled out of their builder’s means, often starting from a precarious shelter and evolving into a spatial and symbolic complex (Pasternak, 2005). The prestige enjoyed by formal order reiterates the urban pathology label carried by the favela’s space; whereas the need to reform its social order – often associated with that of reforming its spatial order - underpins actions such as the one studied in this paper. The removal and resettlement of communities (often to an area in the middle of nowhere) was the standard procedure of public housing policies in the 1960s and 1970s in Brazil. Besides ridding valuable inner city areas of the poor, investors hoped to raise big profits by purchasing large tracts of land in-between the established urban tissue and the new developments, which would be benefited in the long run by public-funded infrastructure.

Reference studies show that modern estates have systematically failed in creating spatial life. In her study of spatial configuration changing patterns in 20th century London, Hanson (2000, p. 100 and 101) affirms that this kind of ‘hard solution” “became so ubiquitous because it seemed to offer a simple way to ensure a stable social order in the rapidly-urbanising slums of the inner
cities, but that in its spatial power simultaneously to concentrate and to separate, lay the seeds of its own destruction”. Hillier and Hanson (1984) point out the disruption of virtual community as a consequence of modern urban design. Alcântara and Monteiro (2010) found evidences of dissatisfaction amongst the population of the community “Abençoada por Deus” in Recife, regarding their virtual “imprisonment” in small dwellings along an orthogonal grid, leaving only “long corridors” (the streets) as open spaces that did not offer conditions for gathering and visual control; dwellers felt exposed to strangers entering the estate. Heitor (2001) reiterates this view by proposing that neglect and vulnerability to antisocial actions is associated to spatial patterns of accessibility, control, visibility and communicability between building and street.

If spatial layout creates or eliminates “life” in the sense that it determines a field of potential encounter and co-presence – a virtual community (Hillier et al., 1987) – the housing estates in Brazil may relate to the modern states examined by Hanson, insofar as they appear to weaken former links of community life. They also reflect an institutional way of thinking in which spatial order brings the possibility of new life patterns: an expression of political force used as a symbolic element of triumph and power (Sobreira, 2003). This paper raises the question that actions like the ones discussed here (old and contemporary), besides materialising deeds of an elitist and unequal society, disassemble a pre-existing social logic and generates unforeseeable impacts on people’s lives and modes of social reproduction.

This study was partially motivated by empirical observation of similar cases in Natal, when one of the authors (Lopes) worked as a trainee architect for the municipality social housing division. She observed, for instance, that former favela dwellers, who had been moved to housing estates, found the need to secure their homes with walls and railings. Thus, the hypothesis that guided her subsequent research (a master dissertation in progress) is that the change of spatial structure from the previous self-built settlement to the housing estates, defines different encounter patterns affecting the daily contacts among inhabitants. Whereas the embedment of the estate in the city’s grid may open the community to the presence of strangers, the former inner logic of encounter may be broken and nexus bonding space and society diluted: a situation that brings to mind Newman’s assertion (1980) that where space and society do not correspond, society begins to breakdown.

“Favela do Maruim” was chosen as case study because it offered the thought-provoking chance of following each reallocation and settling phase. The research began when the population was still living in the favela, being carried on throughout the removal phase, the establishment of the first settlers, the setting up of their homes and the transformation of common spaces and surroundings. An issue to be discussed later in the paper emerged as important from the first settling days as it bears strong connotations with the extent to which dwellers are willing to be open to the town: that of keeping or not keeping the construction fence that was meant to be removed as soon as the occupation process was completed.

Although some similar actions have been recently attempted throughout the country, this study case is still an exception to most Brazilian reallocation processes, because the resettlement happened in a same neighbourhood. It, therefore, offers a particularly appropriate opportunity to test architectural effects as other key variables are maintained – the community remains in the neighbourhood and are able to preserve bonds with former cultural and economic activities, such as the fishing industry and the river.

Granting that the day-to-day activities carried out in shared open spaces were of major importance in maintaining a “sense of community” in the favela, the study explores the nature of those spaces by focusing on the morphological microscale of masses (buildings, fences) and voids (space configuration, entrances, windows) and the limits (interfaces) connecting them, as well as on the physical insertion of the two residential compounds in the perspective of the city. To the purpose of advancing an initial assessment of how the interplay of these variables may affect uses, a preliminary overview about ways in which spaces were and are being used is attempted.

The paper is structured in five items: (i) an Introduction to the problem; (ii) the presentation of the case; (iii) the morphological analysis of the two settlements per se and as to their location
within the city spatial structure; (iv) a panoramic view of the way communal open spaces is used (as per photographs and non-systematic in loco observations); and (v) a preliminary discussion of findings in the light of the central hypothesis.

2. FROM FAVELA TO ESTATE

The first actions for the removal of favelas in Brazil started in the early 20th century, and were largely implemented, under health standards allegations, in major urban centres during the 1950s and 1960s. This kind of action increased the housing deficit, since those dwellings were, in many instances, the only alternative in the absence of public housing policies (Taschner, 1995). The resettling of families to mass constructed housing developments located in peripheral land was intensified in the 1970s and 1980s, and served the purpose of removing undesirable poverty enclaves from central areas (Valladares, 1978).

Favela do Maruim started as a fishing village made up of wooden houses on stilts by the Potengi river, the harbour and the locality known as Canto do Mangue, where fishing boats anchored and delivered their produce to be sold there and elsewhere. The village grew into a settlement occupying federal property with mud-walled and straw-roofed houses (figure 1f), that gradually gave way to brick and tiles buildings, similarly precarious both physically and environmentally, besides vulnerable to floods. Initially the dwellers were predominantly fishermen coming from the state interior, who relied on the river for survival (Bentes Sobrinha; Tinoco; Trigueiro; 2008).

Before reallocation, Maruim occupied an area of approximately 1ha and had 156 buildings of various sizes, ranging from about 4m² to 120m², that sheltered 172 families – some in co-habitation. The reallocation agenda was always present in the life of the community, as they occupied irregularly a valuable central area. In 2000, a neighbourhood rehabilitation plan was designed by the municipality’s administration to expand the harbour and remove the favela. After this, numerous other proposals followed, one having finally been approved in the context of two federal government programmes: the "Programa de Aceleração de Desenvolvimento – PAC", for "accelerating development"; and the "Minha Casa Minha Vida" ("My house, my life"), for reducing the housing deficit (Figure 1d).
The solution found for the harbour expansion was to remove 70% of the area (housing areas), while 30% of the area (commerce at the shore of the river) would remain in the location. In 2013 Natal Municipality, Caixa Econômica Federal (a major government-owned bank) and a private building company began constructing the Residencial São Pedro. The resettling started in July 2016 and is still in progress. A few residents remain in the favela, some of them resisting removal. The housing estate is mostly occupied, and early signs of new modes of social life are being shown. The research following phases shall address this process.

3. SPATIAL ANALYSIS

Architecture, rational or intuitive, is more than a background; it structures a network of inherent relations to human activity (Hillier & Vaughn, 2007; Pssara, 2010). People move through linear spaces, interact with people in convex spaces, and see visual fields from a point in space. Thus, space (and its geometry and topology) is intrinsic to human behaviour, and is the basis for the setting of an actual community (Hillier & Vaughn, 2007). By means of how masses and voids are structured in the built environment, spatial form determines encounter potentials and co-presence amongst different groups – of inhabitants and visitants. The encounter interface amongst different groups is associated with spatial and accessibility patterns (Hillier et al., 1987).

In Latin America, spatial segregation is usually strong among distinct socio-economic classes; marginalized groups, or those with low acquisitive power, tend to concentrate in segregated spaces (Vaughan & Arbaci, 2011). As consequence of urban discontinuity, favelas often occupy left-over spaces, residuals urban lands or empty public areas, such as narrow grounds squeezed in-between barriers, whose growth is limited by the city’s urban mesh. Sobreira (2003) compares this kind of occupation with medieval walled cities. In his analogy, the walls are represented by the social contrast and by the development lines of the predominantly formal city. They can include different morphological patterns, such as a formal layout on the outside, and an informal layout on the inside. This kind of arrangement is clear in Maruim (figure 02). Although located in a neighbourhood integrated with the urban mesh, the space growth is limited by the Potengi River natural barrier, the harbour and the heavy vehicular traffic of the streets Hidelbrando de Góes and São João de Deus. Maruim forms an enclosure, a self-contained structure (Parham, 2015) as only its borders face the outside; the core is more segregated from the rest of the city, only one street allows the entrance of vehicles, the others being pedestrian only. This enclosure causes an effect that Magalhães (1997) calls ‘Marginal Integration’, which may be taken as a defence mechanism against external pressure.
Natural movement impacts on land use patterns by attracting movement-seeking uses, as, for instance, retail, which tends to be located on places with high potential movement (Hillier, 1996), or highly accessible places topologically (i.e. integrated), while non-movement seeking uses tend to be located in places with low potential movement, or low accessibility levels (i.e. segregated). In the case of Maruim, an 'edge economy' (Greene, 1997) takes place: the favela’s borders are the most integrated parts of its spatial compound with reference to the city’s structure, and links the settlement to the ‘Canto do Mangue’, a traditional fishing market. The proximity to the river and the sea helped consolidate this commerce with which the community has always kept ties. According to Lima (2015), 88% of the population show strong bonds with the river and 72% of the inhabitants have their income related to the fishing production, mostly engaged in the cleaning and preparation of seafood for sale. Although being only 700m away from the original community location, in the Residencial São Pedro, the direct relation with the Potengi River – and its fishing commerce for which the population provides service – is lost.

The angular segment analysis (figure 3) carried on for the Residencial São Pedro – as planned – reveals the estate to be more integrated in the city (globally), in terms of through- and to-movement potentials (normalized integration and choice, respectively) (Table 1 and Table 2). Overlaps comprising distinct measurements for potential movement (integration and choice for distinct radii, for instance) are considered prone to mix different activities and people, e.g. visitors and inhabitants (Hillier, 2006; Donegan, 2016; Vaughan et al 2013), a quality viewed by many researchers, since at least Jacobs (1961), as beneficial for urban life. Of the studied situations, São Pedro, as planned, is more likely to favour the mix of visitors and inhabitants. However, if the fences are kept in place the confluence of measures weakens, and as such, the gated São Pedro somewhat resembles the enclosed logic of the favela. In almost all cases (except NAIN at São Pedro as planned) average levels of accessibility are lower than that of Natal’s system, showing that none of the two residential compounds is highly accessible at a global scale, although being close to the city’s integration core (Figure 2). The fences at São Pedro make this the least accessible studied subsystem in terms of global NACH and NAIN.
SHIFTING PLACES AND COMMUNITY LIFE? Comparing Morphology and Uses after a Community Reallocation from a Favela to a Housing Estate in Natal/RN, Brazil.

Despite being more integrated within the city in different scales and presenting a higher confluence between potential movement and intelligibility (in both planned and present situations, 63% and 25% respectively), the estate presents a basically monofunctional residential use. Although its spatial structure is open to the city, São Pedro does not seem inviting for people other than those living there, and it tends to be used mainly as a thoroughfare for passers-by. Maruim is a natural obstructer to the city’s movement. Although its border functions as a magnet (mainly for seafood buying and consumption), the movement of outsiders does not...
enter Maruim. The segregated core, is reserved to community life, with some local commerce (hairdressers, mini markets, bar) offering services to local inhabitants (figure 2). Studies about modes of segregation in Brazil (Monteiro, 2008) show that *favela* occupations tend to favour the notion of Virtual Community, as people in the place feel protected from external threats. In Maruim, a sense of community and self-defence is pointed out by about 77% of the population, which also considers this the main characteristics of their communal living (Lima, 2015).

The self–contained structure is reinforced by the visual analysis (VGA – Visual Graph Analysis). When considering adjacent streets, the *favela* is less visually integrated and consequently less viewed by those who pass outside. Visibility is higher at São Pedro, as there is a straight internal route cutting across most corridors (figure 4).

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**Favela do Maruim** has a street based morphology. Boundaries between public and private spaces are direct, as doors open to the streets, which becomes a public space of recreation, encounter and work (Figure 5). Such configuration can also be associated with life conditions. The space delimited by the urban mesh and by the population financial conditions does not give way for large residences with patios and backyards; the street is an option for activities that usually occur inside the houses, such as washing and hanging laundry, or cleaning fish. At São Pedro, most interfaces are those of windows, as there is only one main receding entrance to each building, and front doors open to the halls inside these buildings. Such public/private interfaces allow for people to peep into some flats through their windows, but the direct access to the street is lost. The configuration ceases to be based on the public space, which loses direct physical contact with the private milieu, as access to flats is in the building’s interior; with buildings scattered in the plot, the streets become residual convex spaces.
Such distancing between the public and the private realms might be even more tantalizing for this community as dwellings in the estate are small. The daily activities that used to happen in the streets at arm’s length are unlikely to recur as the distance between house and street has become greater; neither will people have space to perform such activities inside the estate houses.

4. THE PEOPLE

Preliminary *in loco* observations took place on the following days: 25 June 2016 – at Maruim – (figure 6) and 16 January 2017 – at São Pedro – (figures 6 and 7). The settlements were roamed on foot, at approximately the same hours of the day; pictures and observation notes were taken.

The construction fences are still in place and shall remain there, according to information from the municipal administration until the resettlement is completed and all apartments are occupied. This situation was thus considered in the space analysis, to understand the effects that the present configuration might exert as compared to the planned arrangement, and to explore the possible emergence of relation modes among inhabitants and between them and the built environment within this context. It was observed that the construction fences work as a protection from strangers, and support for some activities – i.e. hanging laundry. Nonetheless, other forms of protection have appeared, such as bars on doors and windows (figure 6).
As to the presence of people in the streets, in Maruim people concentrated on highly accessible spaces (all measures of axial and segment analysis) (Figure 6). In segregated spaces people were engaged in momentary activities (such as hanging laundry) or loitering by. In terms of visual integration, people tended to remain on spots that are visually one step away from most accessible spaces; thus, being able to observe what was happening while not being the centre of attention. Other than passers-by, people gather in most integrated spaces talking in circles on the pavement mostly in spots facing front doors. It was also observed that movement in the streets was surveyed by people from inside the houses. At São Pedro people also seem to concentrate on places close to visually highly integrated places; however, uses are scattered (Figure 7). People were observed to group round the hallway doors to the blocks of flats and in one of the way-ins to the estate on spots more or less privileged in terms of visual integration. Unlike at Maruim, at São Pedro most of the people seen wandering round the estate were children (Figures 6 and 7).
Figure 7 - Uses, interfaces and VGA in Maruim

Figure 8 - Use, interfaces and VGA in São Pedro (with fences).
5. CONCLUSIONS

The Residencial São Pedro was conceived under a geometric order, following contemporary mainstream planning and building, which fails to encapsulate the complex and organic structure of community life (following Hanson, 1989). Although seemingly disordered, the spatial configuration in Maruim encloses an underlying order, which appears to favour certain aspects of community life. Movement is strongly related to the topological and metric accessibility hierarchies. On the other hand, at the estate the regular homogeneous layout of the new buildings leaves only residual spaces for common use, a fact aggravated by there being weak interfaces between the private and public realms.

The spatial configuration in the favela clearly defines a ‘heart’, a central area in which visibility is the highest (from it and, also, to it, as many residents were only one step away, being able to see what was going on, but not being too exposed), and the link between public and private realms was close, thus making a more cohesive entity. In the residential estate, places of visual advantage fail to characterize a community centrality; the public and private realms are physically more separated, both horizontally and vertically – still more so with the existing fences. At São Pedro people persist on staying at open spaces in the estate, but are forced to scatter in small groups, as there does not seem to be a clear centre or confluence of accesses and views. Places where people gather are less continuous to private spaces – as communication is either severed by blank walls or made by windows, most of them high up. This diminishes peoples’ flexibility to move from private to public spheres and reduces natural surveillance (Jacobs, 1961) as compared to that in the case of Maruim.

Regardless of the proximity between the two housing ensembles, the direct link between the favela, the river and the fishing market was broken with the reallocation, disrupting an established social logic. Mixed uses or commercial activities were not contemplated in the planned settlement; the only non-residential uses included in the plans were a community centre, a games court and a children playground. The community centre remains inactive (the community has not had access to the building) and there is not an appropriate place for meetings or developing commercial activities. The relative short occupation time has not engendered, yet, the establishment of spontaneous alternative facilities as had occurred along the many decades of occupation in Maruim. This meagre use mix may be a crucial factor for the dispersal movement of people. The current construction fence helps to convey some similarity with the favela visual and physical segregation logic, so that its eminent removal raises questions as to the residents’ behaviour when the morphological nature with which they were previously familiarised will be fully reversed.

The alteration of built form attributes in the estate – e.g. interfaces, building entrances and economic activities – as compared to the favela, points to a situation that does not favour vitality. The favela’s, spatial and cultural patterns show the ability to thrive as a community, although being an enclave. The estate would, as expected, allow more permeability to the city and potential confluence between inhabitants and visitors. However, this also seems to hinder local community life, as there is not a clear centre, and movement is more likely to split the place in halves. While the planned grid might allow for confluence of movement, from, through and to the surrounding areas, these are not yet present in actual space, so that it prevents discussion about possible benefits that movement can bring to the community’s social life, as fences remain and cut private and public realms.

Findings therefore suggest that the change in spatial configuration has altered the use of communal spaces, and consequently of encounter modes and social interface. Such effects were not considered in the architectural conception and might dramatically undermine the pre-existing sense of community. We hereby underline the morphological investigation of masses and voids – built shells and space – as a powerful tool to assess such changes, and to guide design, by offering knowledge about the interplay of architecture and use that might be considered during conception.
As community life at São Pedro continues changing, further considerations on the effects of architecture on social life are at the core of our following research. These will also address the questions: How will the fence removal affect the community modes of space use? Will the exposure to the city raise intolerance and induce people to stay inside their homes? Or will this lead to the addition of private or semiprivate barriers such as gates and fences? We expect to answer some of these questions as the ampler research, of which this paper reports the pilot study, is completed.
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MULTIDIMENSIONAL STUDY OF URBAN SQUARES THROUGH PERIMETRAL ANALYSIS:
Three Portuguese case studies

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ABSTRACT
This paper addresses one of the most symbolically and socially meaningful elements of the public open space: the urban square (Portuguese: praça). Besides their urban centrality, these spaces’ potential for liveliness depends on multiple factors and their identity as a place may only be grasped by formal methods able to embrace their latent complexity and address the multi-scale and multivariate correlations of factors that defy human cognitive capabilities. This paper presents a synchronic multidimensional analysis of three Portuguese historic squares: Largo da Oliveira, Praça de São Tiago (Guimarães) and Praça do Giraldo (Évora), representative of the national historic heritage.

KEYWORDS
Public Open Space, Urban Squares Morphology, Public-Private Interface, Syntactic Analysis, Multidimensional Analysis

1. INTRODUCTION
The word square by which we translate the Latin – platea – derived terms (piazza, plaza, praça, piață) is used to identify an urban space of exceptional character in the morphology of the public open space. Although usually denoting a designed formal space, in this context we use the term in a broader sense including the informal formations that share a set of particular morphologic and cultural semantic-symbolic values, rooted in history, that make them more than mere
urban voids, pedestrian paths or focal points. In Portuguese, this concept is embodied in other toponymies like largo, terreiro or rossio.

The liveliness and the success of interventions in these spaces is defined not only by their centrality but also by local features like the permeability of their defining planes, besides notions of comfort, security, use and appropriation affordances of a micro urban morphology (Habraken and Teicher, 1998; Gehl, 2011). To address this complexity, a methodology is presented which, collecting contributions from the disciplines of urban morphology and site analysis, resorts to multivariate statistical analysis and inductive patterns search techniques in large datasets by data mining.

The notion of interface, as the potential of a boundary to work as a threshold, is at the very basis of the configurational and morphological analysis, as well as at the basis of the design of the built environment itself (Palaiologou et al., 2016). By discretizing the boundary space of squares, we delve in its potential as interface between architecture and public open space by observing how an a priori set of heterogeneous attributes manifest themselves along their perimeters. The selection of attributes takes an agnostic attitude melding analytical themes (morphologic, environmental, syntactic and functional), scales (global and local) and standpoints (cognitive-unbounded and perceptive-bounded). This strictly data-driven approach is methodologically important in the sense that the proposed inductive data mining methodology is eminently theory agnostic, local (conclusions belong to the data set analysed), and resorts to case-based reasoning (Ahu et al., 2011).

The two cities where the case studies are located (Guimarães and Évora) are paradigmatic examples of the north-south and coast-interior dichotomies of the Portuguese mainland territory, entrenched between Atlantic and Mediterranean cultures (Ribeiro, 2011). Nowadays, tourism and the location of university centres are crucial factors for development of these two medium-sized cities, fostered by UNESCO classification of their historical centres. The three case studies are squares of essentially informal genesis, located in the cities' consolidated historical fabric within well-preserved medieval walls. Nowadays they are carefully preserved symbolic and leisure spaces, located in mainly pedestrianized neighbourhoods where car circulation is not disruptive of their tourist and civic event activity. Besides the considerable difference in area between Praça do Giraldo (Évora) and the squares in Guimarães (Largo da Oliveira and Praça de São Tiago), their historic function was distinct. The Praça do Giraldo (Figure 1) is an example of an ancient rossio: a multifunctional space contiguous to the external side of a city gate (in this case of the disappeared roman city wall), and considered a hallmark of the Portuguese medieval urbanism. These spaces were focal irradiation points for subsequent urban expansions.
Figure 1 - From the top to down: Évora city center, Praça do Giraldo planimetry and photos, Guimarães city center. Praça de São Tiago (b.) and Largo da Oliveira (c.) planimetry and photos. a. and d. in Silva (2009).
Proceedings of the 11th Space Syntax Symposium

MULTIDIMENSIONAL STUDY OF URBAN SQUARES THROUGH PERIMETRAL ANALYSIS:
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(Coelho, 2008). The Largo da Oliveira has a more formal and symbolic character, functioning as the forecourt of the church that dominates and gives its name to the place, while Praça de São Tiago is a classic medieval market square (previously named Praça do Peixe - Fishmarket Square) surrounded mainly by typical houses. Together, these two squares, form an interesting system connected through the archway of the open floorplan of the elevated medieval city hall building. In the presented investigation, they are studied as separated spaces, where each one is part of the context of the other (Figure 1).

2. OBJECTIVES

The main objectives of the presented investigation are: (i) to describe and classify squares’ perimetral space, through a generalizable non-supervised analysis method, which naturally groups sampling points around their perimeter, taking into account a set of heterogeneous attributes simultaneously; (ii) to determine the attributes that better explain functional distribution and morphological diversity along the square perimeter; (iii) to assess how these correlations of factors vary from case study to case study; and finally (iv) to observe how they relate with site surveys and empirical knowledge of those spaces, from the perspective of urban morphology and human behaviour (Gehl, 2011).

3. BACKGROUND AND MOTIVATION

While theory integration between space syntax and urban morphology is mainly carried out at the urban macro scale, e.g. Place Syntax (Stahle et al., 2005), most of its successful and well known practical applications lay at the intermediate scale, between architecture and the city (e.g. Trafalgar square). This follows the schism between planning and design, hindering the development of relations with the typo-morphologic and architectonic stands on the city micro morphologic analysis, that could promote a more sustainable evidence-based urban design.

As pointed out by Palaiologou et al. (2016), the primacy of movement in space syntax theory as the main space usage, rooted in the axial analysis and concepts like natural movement (Hillier et al., 1993) or movement economy (Hillier, 1996), came at the price of privileging the generic city over the complex and culturally specific street-building interface, the lived space in which individual action becomes social practice. Problematising this idea of the street-building interface and claiming for a recalibration of scales, the authors make a stand on the role of constitutedness to shape its own field of encounters, at the threshold of architecture and urban scales, and make a specific contribution to the virtual community concept (Hillier, 1996). One could say that the regularity, and the character of the interface porosity, culturally shape the dynamics of the public space.

The syntactic exploration of the relations between street interface and liveliness has been carried out by authors like van Nees (2007) and Beirão and Koltsova (2015), driven by space syntax seminal ideas like the formalization of the interface relation between private and public realms (enclosed – carrier space) and the ideographic language of spatial arrangements, the morphogenetic model of elementary cell aggregation that gives rise to the bead ring settlement structure, or the constitutedness of space and the interface map (Hillier and Hanson, 1984). At this micro analysis scale the linking between syntax, morphology, typology and architecture becomes natural and the (tridimensional) form and specific aspects gain prominence over the generic and location ones.

The relational or configurational nature of urban space syntax, as the study of the field of possibilities over a discretized system, has the partitioning of the continuum of the public open space at the heart of its theory foundations. Lacking the formal clarity of the axis, the convex space or the isovist (Benedikt, 1979), the translation of urban morphology fundamental elements, like “square”, to a formal language is an ill-defined problem, even if stripped of all its semantic values. However, perceptive and cognitive explorations may cast some light on this threshold problem (e.g. Lynch, 1960; Thiel, 1961; Turner, 2003).
Accepting the square as an urban element per se authors like Campos (1997) and Campos and Golka (2005) investigate the relationship between patterns of use, network configuration and visibility by studying the penetration of axial lines and the effect of visual fields on the space of London squares. Cutini (2003) studies Tuscan historic squares (piazzas), focusing on the relationship between centrality, potential of enclosure, and extension, proposing a new compound visual graph analysis (VGA) index that depicts the hierarchy and performance potential of convex spaces to work as squares.

The classic methods of urban morphologic and syntactic analysis, usually limit the number of variables, to respond to human cognitive and perceptive limitations, restricting the simultaneous expression of features that give spaces their uniqueness. Serra, Gil and Pinho (2013) compile the shortcomings of traditional typomorphological approaches, namely their time-consuming methods, which also restrain the quantity of examples and dimensions considered, and their theoretical partiality.

The identified deficiencies can be handled using new computational methods that allow for multidimensional analysis and typological classifications based on data mining. This interdisciplinary subfield of computer science can be understood as the practical application of machine learning, itself a subfield of Artificial Intelligence (AI) dealing with automatic learning from data (Witten and Frank, 2005). The main objectives of data mining, also known as knowledge discovery in databases (KDD) (Han and Kamber, 2001), are knowledge extraction, prediction and hypothesis generation from data, by favouring an inductive approach. This approach is in opposition to confirmatory techniques, which require a priori hypotheses formulation, and restrict hidden information discovery (Miller and Han, 2001). The automatic learning may be divided in three methods: (i) unsupervised, when there is no a priori labelled data (e.g. used in segmentation, clustering and dimensionality reduction); (ii) supervised, when there is a priori labelled data (e.g. used in predictive models like regression, classification and rule induction); and semi-supervised, when data is partially labelled. Nowadays these techniques are widely applied in many fields of science, engineering and business. When spatial data his involved, like in geographic information systems and geoscience, it is designated by spatial data mining (Demsar, 2006).

Within urban morphological studies, data mining supports analyses at different scales: from Laskari et al. (2008) study on urban identity through quantifiable attributes on blocks' shape at district level, to street patterns in metropolitan areas. Gil et al. (2012), in an unsupervised classification of the urban fabric of two neighbourhoods of Lisbon, focusing on street and block elements, mention the possible integration of these techniques in design. Ahu et al. (2011) explore the potential of supervised learning as a methodology of knowledge discovery in micro urban feature analysis on the historical fabric of a neighbourhood in Istanbul. Chazar and Beirão (2013) point the potential of extending the methodology to deal with non-physical qualities, leading to a better understanding of the public open space morphology. Multidimensional analysis of the latter is rarer: Laskari (2014) analyses the blocks' residual void space in a neighbourhood of Athens, through a set of 13 properties and by different clustering methods. The work of Hanna (2009) on the principal component analysis of graph spectra and self-organizing maps (SOM), and of Al-Sayed (2013) with supervised artificial neural networks (ANN), analysing both design process and the configuration of urban grids, are examples of the application of related techniques in the field of syntactic analysis.

4. DATASETS AND METHODS

Resorting to a previous investigation of the authors on a general method for the multiscale and multivariate analysis/classification of public open space (Lopes et al., 2015), it was chosen a subset of the proposed indicators, that seemed significant to the current study.
Table 1 - Attribute list, metadata and description.

<table>
<thead>
<tr>
<th>#</th>
<th>Att. Name</th>
<th>Unit</th>
<th>Type</th>
<th>Theme</th>
<th>Att. Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SpID</td>
<td></td>
<td>Ordinal</td>
<td>ID</td>
<td>Sp Point ID</td>
</tr>
<tr>
<td>2</td>
<td>x</td>
<td>m</td>
<td>Real</td>
<td>Geo location</td>
<td>Sp point localization x value</td>
</tr>
<tr>
<td>3</td>
<td>y</td>
<td>m</td>
<td>Real</td>
<td>Geo location</td>
<td>Sp point localization y value</td>
</tr>
<tr>
<td>4</td>
<td>z</td>
<td>m</td>
<td>Real</td>
<td>Geo location</td>
<td>Sp point localization z value</td>
</tr>
<tr>
<td>5</td>
<td>PerimCon</td>
<td></td>
<td>Integer</td>
<td>Connectivity</td>
<td>Sp point connectivity</td>
</tr>
<tr>
<td>6</td>
<td>PerimCluster</td>
<td></td>
<td>Real</td>
<td>Connectivity</td>
<td>Sp points Clustering coefficient</td>
</tr>
<tr>
<td>7</td>
<td>IsovArea</td>
<td>m2</td>
<td>Real</td>
<td>Isovist</td>
<td>Area of the Sp point 2D isovist</td>
</tr>
<tr>
<td>8</td>
<td>IsovPerim</td>
<td>m</td>
<td>Real</td>
<td>Isovist</td>
<td>Perimeter of the Sp point 2D isovist</td>
</tr>
<tr>
<td>9</td>
<td>IsovMaxRad</td>
<td>m</td>
<td>Real</td>
<td>Isovist</td>
<td>Maximal radial of the Sp point 2D isovist</td>
</tr>
<tr>
<td>10</td>
<td>IsovComp</td>
<td></td>
<td>Real</td>
<td>Isovist</td>
<td>Compactness of the Sp point 2D isovist</td>
</tr>
<tr>
<td>11</td>
<td>SpsolvOcl</td>
<td>m</td>
<td>Real</td>
<td>Isovist</td>
<td>Occlusivity of the Sp point 2D isovist</td>
</tr>
<tr>
<td>12</td>
<td>VGalnt</td>
<td></td>
<td>Real</td>
<td>VGA</td>
<td>Sp Point Visual IntegrationHH Rn VGA value</td>
</tr>
<tr>
<td>13</td>
<td>VGControla</td>
<td></td>
<td>Real</td>
<td>VGA</td>
<td>Sp Point Visual Control VGA value</td>
</tr>
<tr>
<td>14</td>
<td>VGControlb</td>
<td></td>
<td>Real</td>
<td>VGA</td>
<td>Sp Point Visual Controllability VGA value</td>
</tr>
<tr>
<td>15</td>
<td>VGClastr</td>
<td></td>
<td>Real</td>
<td>VGA</td>
<td>Sp Point Clustering Coefficient VGA value</td>
</tr>
<tr>
<td>16</td>
<td>Fah</td>
<td>m</td>
<td>Real</td>
<td>Facade</td>
<td>Facade height at the Sp point</td>
</tr>
<tr>
<td>17</td>
<td>VFahMax</td>
<td>m</td>
<td>Real</td>
<td>Facade</td>
<td>Maximum facade height of the visible Sp points</td>
</tr>
<tr>
<td>18</td>
<td>VFahSD</td>
<td></td>
<td>Real</td>
<td>Facade</td>
<td>Visible facade height standard deviation</td>
</tr>
<tr>
<td>19</td>
<td>VFArea</td>
<td>m2</td>
<td>Real</td>
<td>Facade</td>
<td>Visible facade area</td>
</tr>
<tr>
<td>20</td>
<td>FaOr</td>
<td>deg</td>
<td>Real</td>
<td>Facade</td>
<td>Facade orientation (y=North=0 degrees)</td>
</tr>
<tr>
<td>21</td>
<td>Max3DDist</td>
<td>m</td>
<td>Real</td>
<td>Facade</td>
<td>Maximal distance to sampled facades (eye h=1.5m)</td>
</tr>
<tr>
<td>22</td>
<td>VSkyF</td>
<td>%</td>
<td>Real</td>
<td>Environment</td>
<td>Sample Point visible Sky Factor</td>
</tr>
<tr>
<td>23</td>
<td>Solar</td>
<td></td>
<td>Integer</td>
<td>Environment</td>
<td>Number of Sp point annual insolation hours</td>
</tr>
<tr>
<td>24</td>
<td>VPpOty</td>
<td></td>
<td>Integer</td>
<td>Constitutedness</td>
<td>Quantity of visible Pp points</td>
</tr>
<tr>
<td>25</td>
<td>MeanDist</td>
<td>m</td>
<td>Real</td>
<td>Constitutedness</td>
<td>Distance to the nearest Pp point</td>
</tr>
<tr>
<td>26</td>
<td>MinDist</td>
<td>m</td>
<td>Real</td>
<td>Constitutedness</td>
<td>Distance to the nearest Pp point</td>
</tr>
<tr>
<td>27</td>
<td>NearUse</td>
<td></td>
<td>Nominal</td>
<td>Use</td>
<td>Land use nearest visible Pp point</td>
</tr>
<tr>
<td>28</td>
<td>VMonum</td>
<td>%</td>
<td>Real</td>
<td>Use Visibility</td>
<td>Percentage of visible Pp monumental use</td>
</tr>
<tr>
<td>29</td>
<td>VPublicServ</td>
<td>%</td>
<td>Real</td>
<td>Use Visibility</td>
<td>Percentage of visible Pp public service use</td>
</tr>
<tr>
<td>30</td>
<td>VHoteiFood</td>
<td>%</td>
<td>Real</td>
<td>Use Visibility</td>
<td>Percentage of visible Pp hotel and catering use</td>
</tr>
<tr>
<td>31</td>
<td>VComerc</td>
<td>%</td>
<td>Real</td>
<td>Use Visibility</td>
<td>Percentage of visible Pp commercial use</td>
</tr>
<tr>
<td>32</td>
<td>VResid</td>
<td>%</td>
<td>Real</td>
<td>Use Visibility</td>
<td>Percentage of visible Pp residential use</td>
</tr>
<tr>
<td>33</td>
<td>VOther</td>
<td>%</td>
<td>Real</td>
<td>Use Visibility</td>
<td>Percentage of visible Pp other uses</td>
</tr>
<tr>
<td>34</td>
<td>BVol</td>
<td>m3</td>
<td>Real</td>
<td>Urban Index</td>
<td>Built volume at Sp point location</td>
</tr>
</tbody>
</table>

They comprise 34 attributes, divided in ten themes, representative of morphological (space shape/built form), syntactic and visibility (connectivity/VGA/isovists), environmental (topography/solar exposure) and functional (permeability/uses) traits (Table 1). Attributes can be global or local, and either the expression of a property at a sampling location or aggregations of values as presented to visibility at that point. Consequently, besides isovists, it is taken another approach on visibility (akin to VGA) as a discrete connectivity graph of the sampling points. Recording the data structure of that graph one can more easily query on connected sampling points’ attributes and aggregate their values in a meaningful manner that may represent the way they express themselves to visibility.
The method implies the definition over the square's models of (i) a square working perimeter and (ii) two sets of points:

(i) The square working perimeter

As a generic rule the perimeter of the square is the minimal polygon (not necessarily convex) enclosed by its built frontage edges and defined by the horizontal and vertical projections of their main façades. As this is an ambiguous description, some assumptions are made clear: existing public ground floor galleries are considered but do not define the perimeter; accessible fenced public spaces that are adjacent to the square are considered part of the square; built façades that partially face the square are considered as an indivisible unit belonging to the square. The proposed perimeters are working perimeters and other definitions may be used, but an effort is made to keep consistency across the case studies.

(ii) Two sets of points

a) Physical permeability points (Pp)

Points located at the centre of ground floor openings (the interface between public and private) in and around the square (with a buffer of approximately 50 meters). These points record the use they serve. Other building openings for lighting, ventilation or views are not considered in this study.

b) Sampling points (Sp)

Points evenly distanced 1.0 m, approximating human scale, numbered and ordered along the squares’ defined perimeter. They work as a neutral referential from which tables are built. The altimetry of these points will depend on the attribute being recorded.

The method implies an initial global configurational analysis of the expanded urban system where the squares are embedded. In the presented case studies, constructed upon Guimarães and Évora municipal georeferenced official cartography, an axial and segment analysis at the urban perimeter scale, and a VGA analysis at their historical centres were conducted (Figures 2 and 3 respectively). The importance of the three squares in their urban system can be depicted on the syntactic maps, and made clearer by mapping Cutini's interaction index $k$ (Cutini, 2003) of the set of squares of those central urban areas (Figure 3).

Subsequently, the focus is directed to urban micro-morphology analysis and local properties, as they are expressed and recorded along the perimeter of the square (Figure 4), using the methodology described above, and in the use of data mining techniques for the visualization and exploration of the datasets so produced.
Figure 2 - Évora (left) and Guimarães (right) segment analysis.
Figure 3 - Évora and Guimarães VGA analysis (1m grid resolution): a. Integration HH, b. Connectivity, c. Clustering Coefficient, d. Control, e. Interaction Index (Cutini, 2003).
Figure 4 - From the top: 3D mass models; overlapping perimetral isovists (from the left: Pr. Giraldo, Lg. Oliveira; Pr. São Tiago); mapping of uses and attributes (Pr. Giraldo).
The first step is to get a sense of the data and validate data quality. Besides data exploratory techniques and descriptive statistics, the mapping of the information is essential for checking out errors and for dealing with outliers. This pre-processing phase includes the normalization of the numeric attributes as identical weight is given to all of them.

Following the objectives, the data is modelled by exploring mainly unsupervised learning techniques: (i) dimensionality reduction, by principal components analysis (PCA), and (ii) partitioning clustering.

PCA allows the determination of a smaller set of artificial variables (the components, formed by a linear weighted composition of the original attributes) that summarize the original data with minimized loss of information. There are as many components as attributes, ordered by their contribution to variance. The first few ones normally attend for the larger amount, allowing to work with fewer dimensions and to produce clearer representations in 2D plots. By analysing the composition of those components, one can filter the most important attributes for further analysis (Witten and Frank, 2005).

Clustering is an unsupervised classification process that assigns objects to groups (clusters), so that the objects of each group are more similar to one another than with the objects of other groups. There are many clustering algorithms; here it is used K-means with the Euclidean distance function, used to express dissimilarity, whose results are easier to interpret. Clustering discovers natural groups of objects or variables, identifies extreme and archetypal examples (based on the distance to the cluster centre: the prototype) and suggests interesting hypotheses about relationships (Witten and Frank, 2005). K-means is here implemented by a derivative algorithm, X-Means, that determines the correct number of clusters based on a Bayesian Information Criteria (BIC) partition heuristic, and balancing the trade-off between precision and model complexity (Pelleg and Moore, 2000).

To assess strong predictors on the location of uses along the square perimeter, Predictor Screening (SAS, 2009) is used; this is a supervised learning method of screening many attributes for their ability to predict an outcome, which is based on random decision trees (bootstrap forest partitioning).

The workflow (Figure 5) implies the functional surveying and mapping of Pp points in the vicinity of the sites, and the creation of 2D and 3D (topographic and volumetric) CAD models suitable for the scale and analysis at hand. The large scale syntactic analyses are produced in DepthmapX (Varoudis, UCL), and the morphologic local analyses using algorithm design software (Rhino/Grasshopper and its plugins Ladybug/Honeybee for environmental analysis) as a mean of gaining control over the analytical tools (Figure 4). For each attribute, data is collected by a specific script and converted in a vector on a multidimensional table. Here simple spreadsheets are used since the case studies are few, but the ideal workflow would include data storage in a central spatial object-relational database (like PostgreSQL extended with PostGIS). For exploratory data analysis and data mining we resorted to the student versions of Rapidminer (RapidMiner Inc.) and JMP (SAS Inc.) and, for visualization and mapping, to QGIS and Rhino/Grasshopper. Data visualization is essential for error checking and for the critical interpretation of the results.
5. RESULTS

The statistical summary in Table 2 (left side) shows aggregated values of the raw data. Some blocks of values appear: Praça do Giraldo concentrates the generality of the highest mean values, as it is the larger space and data is unscaled, and Largo da Oliveira has the lowest attribute mean values related with isovists area, connectivity and VGA, while Praça de São Tiago has the lowest attributes related with isovists perimeter and façades. This last case study, although with high standard deviation, has the highest mean and maximum values of isovist compactness and visible Pp points. These attributes together with the environmental ones, make these Guimarães case studies diverge. The distinct functional character of the case studies is also depicted in the mean values of attributes related with proximity and visibility to Pp points: Praça do Giraldo with commerce, Largo da Oliveira with leisure and monumental buildings and Praça de São Tiago with residential use. Maximum and minimum values are related to squares’ size, the detail of the defined perimeters and the type of attributes (NearUse appears as a 0 or 1 binominal attribute).

The pairwise correlation analysis on Table 2 (right side) shows the pairs of attributes correlated with an absolute value above 0.7, which are mainly the known cases of correlations between VGA, isovists and connectivity, but cross relations with non-syntactic attributes can also be depicted. The negative correlation on the location of residential/leisure and public service uses is also highlighted. Two pairs of attributes have values above 0.95, across all the case studies, so a selection is made on redundant attributes (IsovPerim and VFaArea are dropped off the analysis).

The data presents some outliers but, as they don’t are the result of measurement errors but of idiosyncratic aspect of the sites, the detail of analysis and of the selected perimeter, they are not discarded.

In parallel with clustering, a PCA analysis is conducted, revealing that, in all squares, for an explanation of 95% of the variance of the data about 15 components are necessary, which means a general weak correlation. The first two components explain an average value of 36% of variance and are used in the scatter plot visualization of the clustering results (Figures 6 and 8).
Proceedings of the 11th Space Syntax Symposium

MULTIDIMENSIONAL STUDY OF URBAN SQUARES THROUGH PERIMETRAL ANALYSIS:
Three Portuguese case studies

The clustering process of the Sp points is made in the non-positional attributes (x, y, z), normalized using z transformation (or statistical transformation, where the final data has a normal distribution with zero mean and unit variance) and by the X-Means algorithm. Three clustering experiments are performed: first, a local-individual approach to each square Sp points dataset separately; second, a clustering of the clusters’ prototypes of all the squares; and third a global-joined analysis of all the Sp point datasets from the three squares simultaneously.

The characterization of the clusters (the most distinctive attributes of their class) is made by the comparison of the mean value of the attributes of each cluster (its prototype or archetype), with the mean of all the examples in the dataset, which, with the applied normalization, is zero by definition. So, high and low values indicate values significantly above and below the mean values of the whole dataset (in standard deviations). Figure 6 shows a table of the set of attributes, by square, that include the top five ranking of their normalized absolute value, and the plotting of examples in the first two principal components; and Figure 7 shows their mapping on site. The numbering of the clusters has no special meaning and they cannot be compared across case studies by their designation.

Praça do Giraldo
For this square, there are two major clusters (C1 and C2) whose values concentrate around the global mean (the origin of the coordinates in the scatterplots). Cluster C1 collects all the highest values of solar exposure, VGA control and minimal distance to Pp points. Façade orientation takes low values (good solar south-west exposition), with contrary signal to cluster C2, which concentrates all the highest values of perimetral connectivity, isovist...
occlusivity and VGA clustering coefficient, meaning higher degree of convexity and jaggy visual fields simultaneously (Sp points face the northern gallery). Clusters C3 and C4 gather the extreme examples with values way off below the median regarding connectivity, isovists and VGA, especially isovist area, global VGA integration and controllability as their Sp points are located in a segregated area of transition between street and square, with the highest values of visibility to residential use. Moreover, C3 differs from C4 by the inverse relation in the attributes dominated by the nearby church: VMonum and VFahSD, which records the skyline variability.

**Largo da Oliveira.** In this case study the attributes related with isovists, VGA, proximity to commerce and visibility to monumental buildings separate clusters C1 and C2 from C3 and C4. Extreme high values of the last two features, as well as of visual axis, isovist area and occlusivity, with low value of visible Pp points and related perimetral connectivity dominate cluster C1. The latter are attributes that disentangle C2 from the other clusters, which collect all the high values in the syntactic measures, corresponding to the more central stable space. Clusters C3 and C4 locate mainly in the East side of the square, due more to morphologic and functional aspects than to the value of façade orientation (like in Êvora). The proximity to public services and the built volume of the surroundings, the old convent and church, dominate C3 and distinguish it from C4, what is reinforced by the opposite values of visibility to restaurants and cafés doorways, located across the square, and the skyline silhouette.

**Praça de São Tiago.** This square has two major clusters (C3 and C4) that are the closest to the global mean of this square. C3 collects all the high values of isovists and VGA except the ones related with clustering coefficient (perimetral and extended VGA), due to the concave shape of its urban frontage, as well as solar exposure, along with positive values of visibility to public and touristic services, distinctive traits to C4. The latter collects all the high values of visibility to high façades, with low values of VGA integration.
Figure 6 - Clustering on each square’s Sp points and on the prototypes of all the squares (bottom right). In parentheses: the number of examples.
In the second clustering experiment on the cluster prototypes of all the squares three clusters are highlighted (Figure 6, bottom left). One of the clusters is an outlier with only one example: cluster C1 of Largo da Oliveira. This comes from the extreme positive values of isovist attributes, exclusive proximity to commerce and visibility to the church that diverges highly from the mean values of this dataset. It’s located in a vestibular space to the square and a museum entrance with low visibility to the central space but through which penetrate long axial lines from south and across to the nearby Praça de São Tiago.

The third clustering experiment on the joined datasets of Sp points of the three squares also produces four clusters, individualizing Praça do Giraldo main central space, with the highest mean of Sp’s VGA integration, isovist area and visibility to commerce (Figure 8, top). The outlier cluster of Largo da Oliveira (C2 in this analysis) keeps its independence and Guimarães case studies share clusters C3 and C4 which separate the more segregated and irregular spaces from the main urban frontages. The key features that individualize those clusters are the opposite signs of VGA controllability, sky factor and the quantity of visible Pp points. It’s also possible to observe in the plot of Figure 8 (top left) that Guimarães squares locate in the negative half plane of the PC1 axis, and are well separable from the main cluster of Évora.

In the exploratory experiment using Screen Predictors (SAS, 2009), we analysed the joined dataset of all the Sp points in the discovery of strong predictors on the distribution of uses. Discarding the unidentified uses (Near=Other and VOther) it is defined as our response variable the NearUse nominal attribute and all the others as explanatory ones (Figure 8, bottom). The results are not surprising for Near=Monum (mainly churches in our case studies) as the main predictor is its characteristic extraordinary built volume; public buildings and commercial use have direct configurational related predictors, perimetral connectivity and VGA integration, respectively, corroboration long established space syntax findings; touristic/restaurant activity as well residential use have visibility as their strong predictors. The former has its own visibility as its main predictor, pointing to a clustering phenomenon on its location, and the latter has visibility to commercial use.
6. SUMMARY OF RESULTS AND DISCUSSION

In a critical summary of the results we can assert:

1. Main correlations exist between visibility-configurational related attributes (connectivity, visibility and VGA), and this study shows that their relation to morphologic or environmental ones (e.g. facade area or sky visibility) is highly local.

2. Given the heterogeneity of the attributes, general correlation is low and sharp clusters do not predominate, however their number (four), even if automatically determined, is constant across the analysis of the Sp point datasets (individually and jointly).

3. Cluster description by prototype attribute values is heterogeneous but cross relations are highlighted, capturing some site idiosyncrasies.

4. Key discriminating attributes for clustering (appearing in all case studies prototypes definitions) are mainly, directly or indirectly, configurational.

5. Prototype clustering shows an outlier where the functional features are fundamental for its description, and not only physical or configurational aspects.

Figure 8 - Analysis on the joined datasets. Top: X-means clustering (the plotted squares are not at the same scale); bottom: predictor screening on the use location variables.
6. The joined dataset clustering analysis, separates Évora example from Guimarães’ ones, even if no spatial data is used. Furthermore, it shows some capacity for generalization as clusters appear across squares, but only extremely divergent clusters remain from the local-individual to the global-joined analysis.

7. Attributes related with physical proximity to Pp points (Use attributes) have low expression in clustering. This should be further investigated since in an experiment using a normalization by range [0,1] they gain a greater predominance.

8. Within our joined dataset universe, strong predictors analysis on use location corroborates the predominance of configurational related attributes as main predictors. An interesting finding is the visual clustering phenomena of touristic/restaurant activity location, as its strongest location predictor is its own visibility.

The empirical analysis of the relation of people’s appropriation of space with the spaces defined by the clustering of Sp points seems, for instance, to corroborate the preference for highly clustered convex spaces in the location of terraces (Figure 7, e.g. Praça de São Tiago). However, these spaces are highly conditioned by the potential of transformation of built typologies, mainly their ground floor, and by peripheral car circulation which tends to segregate the more domestic sides of the squares.

7. CONCLUSIONS

Going beyond a perimetral syntactic analysis, as possible in Depthmap, or a shape analysis by perimetral connectivity, like in Psarra and Grajewski (2001), the present study illustrates a specific method for the analysis of the urban square, which tries to capture its latent complexity. Taking a stand on the micro urban morphologic analysis and the individuality and potential of the perimetral space to work both as interface between public - private and architecture - urban space, this space is synchronically and multidimensionally analysed in three Portuguese case studies resorting to data mining techniques. These seem to be most appropriate to support a data-driven approach that tries to blend standpoints, scales and themes of analysis, reasserting the centrality of the study object, the urban space/square, in the realm of the varied field of the urban studies.

Although our approach is eminently analytical, its application to design can be envisaged in a strategic level. In fact, it can help in promoting a more evidence-based design and to gap the barriers between analysis, decision and project, resorting to case-based reasoning, which is inherent to the presented methodologies.

We should stress that the analysis is highly sensitive to the a priori definition of the perimeter and to the data normalization methods. In future work these issues should be addressed, as well as clustering quality measures and the analysis of the frontier between clusters (both in urban and data spaces).

The basic concepts in which we delve are, beyond shape and proximity, visibility and permeability, which in the space of the square have a particular character. While in the channel space of the street the intervisibility of façade and permeability are defined mainly by bilateral frontality, in the square that affinity is augmented by the presence of third elements in lateral relation. This kind of relation mediated by a third element is exactly at the root of configurational analysis and complexity itself (Poincaré’s three-body problem).

New tools (concrete and conceptual) impelled the space syntax project in the 1980’s, namely graph and network theories, and backed up its structuralist approach (Hillier, 1996). As the theory fundamentals get stabilized, its boundaries get more convulsed, and amidst a data driven society a new set of tools seem necessary to support our cognitive limitations and open new frontiers. Data mining and machine learning are therefore proposed here as methods, not only of systematic analysis on urban data and hypothesis testing, but also hypothesis creation and speculative devices.
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CONFIGURATION OF SELF-ORGANIZING INFORMALITY:
Socio-spatial dynamic in favelas

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ABSTRACT
This paper aims to discuss on spatial patterns found in favelas throughout different cities worldwide, as they seem to reproduce similar configurations and urban dynamics despite its diverse local contexts. The purpose is to explore these patterns in order to understand its social behaviour and address urban informality issues through it. To see how resilience seems to be inherent to such spaces, that grow vibrant, complex and dynamic global structures emerging and self-organizing from segregation in city space. It pursues the acknowledgement of structural morphological patterns of informality production, those genotypic characteristics that seem to be independent on culture, and might be representative of these social patterns commonly observed worldwide. Favela is observed in this study as a complex, self-organized entity, whose contrast to official city relies on its “bottom up” structure. It tends to follow natural rules of organization instead of formal urban strategies. Space Syntax (Hillier and Hanson, 1984) is the theoretical and methodological approach applied, through which it is possible to investigate these peculiar spatial patterns in favela, comparing several cases in Latin America, Africa and Asia. The analyses are based on axial and segment maps. Investigated variables are connectivity, local and global integration, mean depth, synergy, intelligibility, angular Choice, number and length of axes, and number and length of segments, compactness, normalized angular integration and choice for segment comparison. Findings show favela as an entity that maximises use and space into strong fragmented spatial structures, which provides the labyrinthic perception of users, but also accentuates spatial hierarchy. Topography is critical to the understanding of favela’s performance. The more accentuated, the more fragmented, labyrinthic and endogenous. Nevertheless, most analysed favelas locate in flat areas and, therefore, present a tendency to better articulate with the surroundings, resulting in a softer in-and-out transition. Such topological performance seems better than Brazilian cities (Medeiros, 2013), which points out favela’s organizing structure as a possible model that could be adopted to refine the configurational performance of cities.

KEYWORDS
Favelas, Self-organizing Informality, Spatial Patterns, Space Syntax.
1. INTRODUCTION

This paper explores favela’s urban form through a spatial perspective, discussing the use of configurational tools for a systemic reading of space according to The Social Logic of Space (Hillier & Hanson, 1984; Hillier, 1996). The main goal of this exploratory research is to identify the spatial structure of such settlements, observed as spontaneous and emergent practices in the urban systems. This goes accordingly with the research question “Is there a spatial pattern for favela?”.

The study is supported by the acknowledgement that built space is at the same time cause and result of social dynamics, being profoundly connected to the social agents responsible for build and occupy it. As a self-built and self-organized object of study, the favela is observed within its level of complexity throughout its architecture, understood as the whole form (solid) and space (void) relation interpreted in its urban scale.

As Sobreira highlights, favelas are self-organized entities as well as self-similar in itself and with each other, referring that spatial patterns of favelas in Recife or Bangkok tend to superimpose to cultural or political specificities due to a universal need for space optimization (Sobreira, 2003). Such premise reveals the possibility of common rules of organization in urban structures suggesting an also common formative process and social dynamics.

Favela’s built form tends to be misunderstood due to its complex spatial rules, result of self-organizing processes that strongly differ from official city regularity and formality. It represents some kind of fractal order that cannot be clearly read by observation and constitutes space as an irregular and fragmented entity (Sobreira, 2003). Fractal, in built space, can be defined as a property of a set of spaces which form is extremely irregular or fragmented and present the same structure in all scales (Sobreira, 2003). This means that favela as a self-organized entity has some implicit rules that allow the individual action taken by all agents collectively to organize and structure it.

Such level of urban complexity is not exclusive for favelas. Salingaros (2013) recognizes it as effective part of diachronic city process that often results in organic cities. For the author, by looking at the timeline of settlements it becomes clear that modern planning and design is the most simplifying of all, distancing itself from human scale and adaptability. Therefore, favela might be erroneously considered as the absence of intention, as Medeiros criticizes (2013), when evaluated by the optics of present day urban planning. But once observed its structural self-organizing processes, it is possible to acknowledge some highly strong adaptation and resilience levels that seem to lack in formal spaces.

There seems to be a strong similarity among these organic or informal settlements, particularly subsidized by its generating order. Once planned “top down” spaces apparently organize formally in accordance to imposed urbanistic rules and laws, self-organization works “bottom up” and generate self-similar and organic structures that tend to evolve and adapt more efficiently.

2. DATASETS AND METHODS

Starting from the introductory theoretical background that relates the global dynamics of urban systems to the emergence of specific organizing rules, it becomes clear that space/society relation is a relevant key to understand urban space. So, a search for how space acts and performs is developed through the Social Logic of Space Theory (or Space Syntax) originally created by professors Bill Hillier and Julienne Hanson at London UCL (Hillier & Hanson, 1984).

The research is structured by the aim of understanding spatial patterns in self-organized informal settlements – named generally as favelas in this paper – and so, the type of spatial informality studied here is that of organic form and decentralized (or emergent) building processes. Such definition is product of research interest in spontaneous (and informal) urban processes in contemporary cities, therefore excluding other types of informal/illegal settlements from study. From this starting point, the case studies were selected according to visual quality of available satellite images of large unequal cities worldwide (based on GINI index and World Bank data.
for population and urban population living in slums). This resulted in the initial selection of 30 cases from 12 countries that were comparatively analysed through its axial and segment maps: Angola (Musseque 01, 02, 03 and Musseque Sambizanga in Luanda), Bangladesh (Favela 01 in Dhaka), Brazil (Moura Brasil and Lagoa Coração in Fortaleza, Heliópolis, Jaqueline and Jardim São Luis in São Paulo, Timbau, Jacarezinho, Vidigal, Rocinha and Providência in Rio de Janeiro, Vila Barragem in Belo Horizonte), China (Favela 01 in Beijing and Favela 01 in Shanghai), Egypt (Favela 01 in Cairo), Yemen (Favela 01 in Sanaa), India (Favela 01 in Ahmedabad), Lebanon (Favela 01 in Beirut), Malaysia (Favela 01 in Johor Bahru and Favela 01 in Penang Island), Mozambique (Caniço 01 and 02 in Beira and Caniço 01 and 02 in Maputo), Thailand (Favela 01 in Phuket) e Turkey (Favela 01 in Istanbul).

The studied sample of favelas was identified through a set of configurational variables, presented in table 1. After individual analysis of the 25 variables, some measures were correlated in order to find data associations, contributing to the exploitation of what might be the spatial pattern present in favelas.
**NAME** | **DEFINITION** | **SIGNIFICANCE FOR ANALYSIS**
--- | --- | ---
Name | -- | --
Country | -- | Location
Geographic Region (UNESCO) | -- | Location

**QUALITATIVE**

<table>
<thead>
<tr>
<th>NAME</th>
<th>DEFINITION</th>
<th>SIGNIFICANCE FOR ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>Flat slope, Moderate slope or Steep slope</td>
<td>Context</td>
</tr>
<tr>
<td>Size</td>
<td>Large, Medium or Small (according to kohlsdorf's procedures, 1996)</td>
<td>Dimension</td>
</tr>
<tr>
<td>Position in urban context</td>
<td>Inserted in continuous fabric, Peripheral, or Peripheral on hill</td>
<td>Context</td>
</tr>
<tr>
<td>Position of Integration Core</td>
<td>Most integrated lines or topologically most accessible ones tend to be Internal, Peripheral or Mixed</td>
<td>Centrality</td>
</tr>
<tr>
<td>Form of Integration Core</td>
<td>Linear, Deformed Wheel (Hillier &amp; Hanson, 1984) or Mixed</td>
<td>Centrality</td>
</tr>
</tbody>
</table>

**QUANTITATIVE - PHYSICAL**

<table>
<thead>
<tr>
<th>NAME</th>
<th>DEFINITION</th>
<th>SIGNIFICANCE FOR ANALYSIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>N° of Lines</td>
<td>Total of axial lines in each favela</td>
<td>Dimension</td>
</tr>
<tr>
<td>Area</td>
<td>Favela’s area in km²</td>
<td>Dimension</td>
</tr>
<tr>
<td>Total Line Length</td>
<td>Sum of all lines length in km</td>
<td>Dimension</td>
</tr>
<tr>
<td>Compactness A</td>
<td>Reason between number of lines and area, in lines/km²</td>
<td>Density</td>
</tr>
<tr>
<td>Compactness B</td>
<td>Reason between total length and area, in km/km²</td>
<td>Density</td>
</tr>
<tr>
<td>Line Length</td>
<td>Mean length of axes in linear representation</td>
<td>Mean length in the street system</td>
</tr>
<tr>
<td>No of Segments</td>
<td>Total amount of segments in each favela</td>
<td>Dimension</td>
</tr>
<tr>
<td>Total Segment Length (km)</td>
<td>Sum of all segments in the favela, in km</td>
<td>Dimension</td>
</tr>
<tr>
<td>Segment Compactness A</td>
<td>Reason between number of segments and the area of the settlement, in segments/km²</td>
<td>Density</td>
</tr>
<tr>
<td>Segment Compactness B</td>
<td>Reason between total segment length and the area, in km²/km²</td>
<td>Density</td>
</tr>
<tr>
<td>Segment Length (m)</td>
<td>Mean length of segments in the segment map</td>
<td>Mean block’s size</td>
</tr>
<tr>
<td>N° of Segments/No of Axial Lines</td>
<td>Reason between the number of segments and number of axial lines in each favela</td>
<td>Level of orthogonality: an higher number reveals orthogonal tendency (much more segments than axes) a smaller number reveals a non orthogonal, or more organic structure</td>
</tr>
<tr>
<td>NAME</td>
<td>DEFINITION</td>
<td>SIGNIFICANCE FOR ANALYSIS</td>
</tr>
<tr>
<td>--------------------</td>
<td>---------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Connectivity</td>
<td>Average of connections per line</td>
<td>Related to an higher or lower quantity of routes and paths</td>
</tr>
<tr>
<td>Integration HH Rn</td>
<td>Mean value of global integration (calculated according to Hillier &amp; Hanson, 1984) representing mean global topological accessibility</td>
<td>It addresses the ability to move easily through space according to configuration, also influencing on land use and main centrality formation</td>
</tr>
<tr>
<td>Integration HH Rn Base 100</td>
<td>Mean value of global integration (Hillier &amp; Hanson, 1984) weighted according to Medeiros, 2013, representing the degree of mean global topological accessibility of studied settlements in a scale from 0 to 100</td>
<td>Addresses movement, land use and main centrality for settlement comparison</td>
</tr>
<tr>
<td>Local Integration HHR3</td>
<td>Mean value of local integration calculated according to Hillier &amp; Hanson, 1984 representing the degree of mean local topological accessibility</td>
<td>Observation of local movement, activities and centralities in favelas</td>
</tr>
<tr>
<td>Synergy</td>
<td>Correlation coefficient between global integration and local integration</td>
<td>Synchrony among local and global parts of the system, affecting on spatial perception</td>
</tr>
<tr>
<td>Intelligibility</td>
<td>correlation coefficient between global integration and connectivity</td>
<td>Expectation of highly connected lines to be also the highly integrated, affecting spatial perception of place</td>
</tr>
<tr>
<td>NAIN</td>
<td>Normalized angular integration, normalization for the measure of integration in segment maps</td>
<td>Mean values for topological accessibility, enabling settlement comparison without scale distortions</td>
</tr>
<tr>
<td>NACH</td>
<td>Normalized angular choice, normalization for the measure of choice in segment maps</td>
<td>Analyses the through movement or hierarchy of path in the settlement, enabling comparative analysis without scale or size distortions</td>
</tr>
</tbody>
</table>

Table 1 - Variables used in study
The selected settlements are part of a larger database that has been built along a PhD developing research. The analysed maps were drawn through free satellite images accessed from GIS platform QGIS©, and processed in Depthmap© for the calculus of configurational measures.

In terms of favela representation, it was chosen to draw only its informal structure, which means that all maps are represented disconnected from the remaining urban fabric. Taking into account the aim of analysing the internal structure of the favelas, the edge effect (weighting factor when analysing a small fragmented part of a larger system, according to Medeiros, 2013) had to be disregarded. This happens due to the extreme difference between favela organic structure and the surrounding city grid. As shown in figure 1, the experiment of representing favela following the common procedures – considering the edge effect – as well as only its structure – without outer connections –, resulted in some differences that seemed relevant for the analysis. As it is possible to observe in first situation, centrality is pulled towards the city grid while the purpose of research is to analyse and infer about the internal structure of favela. The reading of internal relations is much more relevant for addressing the research question, and that the larger surrounding grids might negatively affect such observation, so this methodological change had to be made. Also, due to its nature and organizing process, favela is in some way denied and denies the evolving city, this meaning a fragile connection between the surrounding and internal networks that explains the structural differences and peculiar method for addressing it.

Figure 1 - Experiment of representing a favela - Heliópolis (São Paulo) - with edge effect (left) and without it (right) in order to choose the best procedure for observing favela’s internal structure.
3. RESULTS AND DISCUSSION

3.1 PHYSICAL STRUCTURE AND ACCESSIBILITY

The following results explore the research question aiming to identify a pattern in the analysed sample of favelas. For a comparative overview, the obtained data is confronted with measures from 44 Brazilian cities investigated by Medeiros (2013). Also, mean values are highlighted to approach and verify the diversity in the settlement selection.

Following the bases of topological accessibility, the investigation of relational dynamic in favela happens from evaluating the paths network interdependencies. Preliminarily it seems important to explore connectivity (Figure 2), which, by the reading of axial maps, represents the average count of connections in each street of a given system. There is a great diversity of results, the analysed group contains values up to 4.0, superior to the 3.86 of Brazilian cities in general (Medeiros, 2013). Nevertheless, the mean value stays at 2.97, pointing out that these settlements have a lower amount of connections and therefore a smaller quantity of routes and paths possibilities. In the absence of some mitigating features, this seems to promote a labyrinthine character in space associated to its highly-fragmented structure.

![Figure 2 – Mean connectivity](image)

The commitment to interdependency relations results in associating the lower values of connectivity with favela’s organic character. Here, however, a relevant fact emerges. The mean value for integration HH in favelas (figure 3) (0.840) – representing the accessibility levels in paths network, weighted in a way that systems size will not influence the results – is superior to the one of Brazilian cities (0.764). One believes that this might occur due to the patchwork pattern recognized in Brazilian urban systems (Medeiros, 2013) and also due to the fact that local-global relations seem more efficient in favelas (cf. Figure 8 to synergy and intelligibility values). Although favela presents a better configurational performance, such characteristic does not mean that it might be already considered positively. Both present structural issues to understand, either related to homogeneity or fragmentation. Anyway, opposing to a negative established perspective, there seems to be a set of positive configurational relations in favela needing further investigation.
A slight inversion can be found in integration measures when converted to base 100 normalization (figure 3). In this case, when the distance between the mean value and poles is evaluated (all cases are converted to fit a range of minimum 0 and maximum 100) it becomes clear that hierarchy is higher in favelas than in the Brazilian cities sample (Medeiros, 2013): 43.3 in favelas and 47.3 in Brazilian cities. Such perspective points out to a greater level of segregation in favelas, once the topological distance between the integration extreme (integration core) and the mean is higher than in the observed cities. This results in a much-closed urban space which can be related to favela’s endogenous character.

More refined accessibility measures can be extracted from segment maps and evaluated through angular differentiations in linear models. Considering that integration measures reflect topological accessibility (centralities and peripheries) and choice comprehends the most used paths (road hierarchy), NAIN and NACH represent normalized weighting to both (figure 4). A systems hierarchy tends to be better defined (consisting in efficient through-movement) if a higher NACH value is presented, whilst potential accessibility is better distributed (efficient to-movement) with a higher NAIN value. Even though this part of analysis has no comparison to Brazilian cities, findings suggest that topography plays a significant role in the type of settlement and therefore the established urban grid. It seems evident to both cases that more connected/regular settlements are located in the graphics superior poles.

The relevant cases of bigger levels of connectivity (figure 2), NAIN and NACH (figure 4) are Caniço 02 in Beira, Musseque 01 in Luanda, Favela 01 in Sanaa, Favela 01 in Beijing and Shanghai and Caniço 02 in Maputo. On the opposite side, characterized with low connectivity, higher irregularity and also lower NAIN and NACH are found Brazilian settlements mostly, such as Providência, Vidigal, Jardim de São Luís and Rocinha which represents a recurrent scenario of steep slope type of settlement. Nevertheless, Rocinha seems to be a peculiar situation once it presents a medium value for connectivity (2.86 in 2.97 of global mean) and the second smaller NAIN. This might be related to the intensity of topography and the large and complex scale of 8,453 lines system.
Figure 3 – Integration HH (Top), Integration HH Base 100 (Bottom)
Figure 4 - NAIN (Top) e NACH (Bottom).
3.2 CONFIGURATION AND TOPOGRAPHY: DISPERSION AND ASSOCIATION ANALYSIS

The following dispersion analysis confronts connectivity, integration, NAIN and NACH values with the qualitative categories world region and topography (figure 05). Two main and interdependent tendencies stand out: (1) Latin-American settlements (represented here by Brazilian favelas) have the worst performance, being located at the graphics bottom. This result might be produced by the recurrent steep slope settling of favelas in Brazil and the consequent results mentioned above. Either way, independently of geographical location it is observable that (2) places with accentuated slopes have lower levels of accessibility. This reinforces the relevant role played by topography over the type of urban grid generated in space. Flat urban structures show tendency to be more accessible than sloping ones.

Figure 5 – Dispersion graphics associating: (a) connectivity and integration Rn HH with geographical location (top. left), (b) connectivity and NAIN with geographical location (top, right), (c) NACH and NAIN with geographical location (bottom, left), and (d) NACH and NAIN with topography (bottom, right).

Despite the diversity of existing scenarios, the relation between topography and favela is strongly integrated into Brazilian urban imaginary once such spaces are deeply associated with steep areas – morros. Nevertheless, the association of topography with area (figure 6) reveals that favelas in flat sites are the most common situation in all size categories (large, medium and small). Most settlements, it seems, are located where occupation process might be facilitated in terms of aclivity, notwithstanding the common environmental issues of such areas (floodplains, swamps, lowlands, and so on).

A similar tendency is shown in the association between topography and position in urban context (figure 6). Favelas located in continuous urban fabric prevail to all others, and those are commonly situated in flat areas. The same happens to the cases in peripheral areas, with exception of those on hill situation.
Topography also seems to affect the form and position of integration core (figure 7). The ICs recognized as deformed wheels are only located in flat areas, while the remaining – linear and mixed – can be found in all three topographical categories. This opens discussion about consolidation processes in top of hill favelas. Would a deformed wheel structure develop and emerge even in a restricted relief situation, or do physical constraints prevent such consolidation process to develop? This might explain about favela’s weak relations to surroundings when located in extreme relief areas.

Nevertheless, internal integration cores mostly happen in structures located at steep sloped areas (figure 7), reinforcing the idea of favela as an almost autonomous system when located in such conditions. The articulator role of external accesses in favela seems to be reduced when no central lines connect to it, once the structure is not sewing to surroundings. This might be related to the configurational process for ghetto formation.

Measures of topological accessibility, when confronted with topography, can express how much physical constraints do affect on among parts articulation. Previous studies, such as Medeiros (2013) pointed out, looking at colonial cities, that relief tend to result in more fragmented systems once it produces a network of mostly “T” shaped paths. This means that routes usually end right after connecting, without crossing. Oppositely, in flatter areas, city structure seems to progress towards orthogonality, presenting a prevalence of “X” paths and intersecting a larger number of streets. The main effect on accessibility relations in the first situation is that global paths are critical for connecting central and peripheral parts, otherwise movement and route options will be restricted. In the second situation, when connections are maximized there will be more path options, causing smaller polarization within accessibility extreme conditions. And so, even in organic structures, it is important to observe some favouritism over access routes in order to assure significant reduction in the labyrinthic effect of spaces (negative for quality urban spaces, damaging perception and comprehension processes over built space and reinforcing segregation by impeding basic services access or even discouraging visitors).
The obtained results in figure 8 suggest the extent to which topography restricts accessibility. Favelas located in flat areas show higher mean connectivity values (3.15), while in steep or moderate sloped areas the mean decreases below 3 (the global mean is 2.97) and Brazilian cities investigated by Medeiros (2013) reach to 3.86 (figure 8).

![Figure 8 – Variables association: topography, integration Rn HH, NACH, NAIN and connectivity.](image)

The performance of integration HH Rn, NAIN and NACH measures reinforces the tendency. However here, the more accentuated, the lower the value is and the flatter, the higher it becomes. This means that topography results in a set of constraints for the implementation process that can compromise topological accessibility, as seen before.

It is worth clarifying that mean integration HH of favelas (0.840) is higher than that of Brazilian cities (0.764) (as seen in figure 03). The negative factor impacting on the performance of these cities – the worst in a comparative study for cities worldwide (Medeiros, 2013) – is the so-called patchwork pattern. Brazilian city is generically regular but composed over adjacent distinct grids from different neighbourhoods or city zones, lacking global connections to coherently articulate the parts. In the case of favelas, despite the impact of topography, there is a clear spatial pattern distributed in all system, generating higher homogeneity and also better hierarchy. And perhaps, that is the source of favela’s better performance. Still, it seems critical to consider a scaling factor when analysing the results (even though integration values are already normalized in order to guarantee comparison): smaller systems commonly have higher accessibility values. While Brazilian cities have a mean of 7,882 lines, favelas reach only 834.

It is also important to verify some recurrent pattern relating topography to spatial perception matters (figure 09). The more accentuated the site, the more compromised are the relations between local and global parts of the system read through intelligibility and synergy measures. The first expressing the expectation of most connected lines to be also the most integrated ones (integration HH), and the second expresses the prediction of globally most integrated lines to be also the most integrated locally (the global dynamic expressing itself on local dynamic). Results present that favelas in flat areas are easier to read: intelligibility and synergy values are higher in those cases, while smaller values can be found in steep sloped systems. It seems to be the case that they can be easily recognizable from outside, due to its outstanding position, although this physical condition accentuates the labyrinthic character of its constituent paths network.
Comparing the obtained values to the values of Brazilian cities, available from Medeiros (2013), once again the patchwork pattern becomes relevant (figure 10). Despite problematic issues in urban systems like favelas, there seems to be a better spatial perception performance than in the urban systems of Brazil. This seems to be simultaneously product of size and among parts articulation, due to urban fragmentation. Although often related to labyrinthic scenarios, favelas seem to keep better internal relations due to a clear hierarchy among main accesses or central lines in the integration core and the alleys and paths integrating the remaining system. Though both cases present low values, favela’s intelligibility is 22% while it is only 15% for Brazilian cities. Moreover, mean synergy in favelas is 50% opposing to the 36% of cities.
Figure 10 – Intelligibility (top) and synergy (bottom).
4. CONCLUSIONS

As an exploratory research, this paper aimed to identify the spatial structure of favela among recurrent spontaneous urban practices. Discussions were based on the following research question: “Is there a spatial pattern for favelas?”. Findings suggest a set of tendencies for a better understanding of spatial patterns in those settlements, referring to topological characterization and topographic relations:

- Topography constraints favela’s accessibility. Settlements in flatter areas have higher mean connectivity values, when slightly sloped or steep sloped (without expressive distinction) mean values fall down. Performances of Integration HH Rn, NAIN and NACH reinforce the tendency. However here, the more accentuated, the lower the value is and the flatter, the higher it becomes.

- As for perception matters, it is also possible to find a recurrent pattern in relation to topography. Global and local relations from synergy and intelligibility tend to be more compromised as more accentuated the place’s topography seems to be. Despite that, spatial perception is better in favela than in Brazilian cities. This seems to be simultaneously product of size and among parts articulation, due to urban fragmentation. Although often related to labyrinthic scenarios, favelas seem to keep better configurational relationships due to a clear hierarchy among main accesses or central lines in the integration core and the alleys and paths integrating the remaining system.

- The mean values for topological accessibility are higher in favela than in cities (cf. Medeiros, 2013). Such performance seems to result from, at first, the patchwork pattern present in Brazilian cities, and secondly, from the presence of more efficient local/global relations in favelas than in those cities. Such characteristic does not mean that it is already something considered positively. Both present structural issues to understand, either related to homogeneity or fragmentation.

- Spatial hierarchy is clearer in favela than in cities which can be related to its endogenous and complex character, possibly resulting in a much closer urban space.

The synthesis of findings assumes a spatial pattern for favela:

- Compact and dense structure, due to a maximization need of land use, even in flat areas (predominant);
- Predominance of short streets and irregular urban blocks;
- Resulting into meaningful fragmentation and discontinuity, affecting mainly on the labyrinthic perception of space;
- Accentuated spatial hierarchy (minimum and maximum poles being more distant, resulting in reinforced segregation);
- Topological performance better than Brazilian cities.

Such characteristics, specifically this last point reinforces to the need of acknowledging furthermore the existing relations in favela that could be adopted to refine the configurational performance of cities. Nevertheless, topography is critical to the understanding of favela’s performance. The more accentuated the more fragmented, labyrinthic and endogenous. Oppositely, flat settlement areas present a tendency to better articulate favela with the surroundings, resulting in a softer in-and-out transition.

As it seems, the spatial structure of favela experiences, in a very short period of time since its implementation, a transforming process that city took decades or centuries to achieve. Due to its occupation restrictions, the spatial organizing rules are dynamic and can be observed in diverse development stages. The self-organizing and emergent processes of favela provide clues to how and how much space is transforming progressively, without top down agents or global planning, in order to ensure better global and local relations into the efficiency of life in community.
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IN SEARCH OF A NEW CENTRALITY MODEL
Linking spatial network analysis, employment density and public transport networks in the city of London

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ABSTRACT
The paper can be read as an extension of previous studies on urban centrality. Using space syntax as a theoretical and analytical tool, the paper investigates the relationship between employment density, spatial accessibility and public transport, and how they each influence the understanding of urban centrality in the city of London. The general hypothesis of the research is that by linking spatial network, employment density and public transport, a more advanced model can be provided in understanding centrality in cities. Meanwhile, a more efficient methodology can be obtained for usage in urban planning and urban design. It is argued that both employment density and spatial accessibility are significant indicators of urban centrality. Spatial analysis is able to supplement and enhance the understanding of the employment-based centrality, which can be further enhanced by taking public transport system into consideration. In its search for a more advanced understanding of centrality, the study aims to develop a hybrid model of centrality that brings all of these influencing aspects into one single model. It is suggested that such a model is able to build an advanced profile of urban centres, which could serve as a tool to describe, evaluate and predict the centrality pattern of the city. This approach is proposed to be integrated in urban studies, urban design and urban planning processes for cities on various scales.

KEYWORDS
Urban Centrality, Employment Density, Spatial Accessibility, Public Transport System, Hybrid Model

1. INTRODUCTION
The issue of centrality is widely discussed in both urban economics and spatial studies. In a metropolitan city like London, centralities of different scales are emerging, developing and shifting all the time. Therefore, there is a need to look beyond a singly defined concept of centrality and look at how different aspects draw impact on the dynamic pattern of centrality and how they can re-define it.

This research aims to search for an advanced model in understanding urban centrality of London. The intention is to find out a tool that can describe the particular spatial and socio-economic features of centres. In doing so, this paper first explores the relationship between employment density, spatial accessibility, and underground network, and how they each influence the concept of urban centrality. On basis of these analytical results, attempts are made to integrate these elements into a hybrid model that can more accurately and specifically capture the centrality pattern of the city.
In Space Syntax literatures, numerous studies have already focused on the relationship between spatial configuration and socio-economic performance. This study serves firstly as continuation of these studies by investigating such a relationship on urban centres. Moreover, it attempts to establish a joint analytical model of centrality by combining both spatial data and socio-economic data. In other words, efforts are made in this paper in order to integrate the ‘structural component with the phenomenological component’ (Marcus 2007, p2) of urban centres. It is proposed that multiple measurements should be taken into consideration in one general model and it is believed that such a method would be of great value in urban planning and urban studies.

One of the common ways of identifying urban centres is to use the measurement of employment density, as it generally captures the economic vitality of an area. However, it is believed that such a method is not able to cover all situations. Therefore, this study brings Space Syntax analysis and public transport into discussion and attempts to find out how they are able to enhance the understanding of centrality. The general hypothesis of the research is that by linking spatial network, employment density and public transport, a more advanced model can be provided. Meanwhile, a more efficient methodology can be obtained for usage in urban planning and urban design.

On basis of the hypothesis, the first research question would be: How does spatial analysis enhance the understanding of urban centrality that is based on employment density? In order to answer this question, three sub-questions are investigated:

- To what extent is the measure of employment density able to identify urban centrality?
- To what extent is the measure of spatial accessibility able to identify urban centrality?
- What is the relationship between employment density and spatial accessibility and how does this relationship differ from centres to non-centres?

The second question is: How does underground network affect the concentration of employment and the emergence of centrality? Would it further enhance the understanding of urban centrality if taking public transport network into consideration?

With the above two questions, the third research question would be: If employment density, spatial accessibility and public transport network each has their role in understanding and identifying urban centrality, would a hybrid model integrating these aspects contribute to a more comprehensive understanding of urban centrality? If so, how should this model be built and how could it be applied to urban studies?

2. DATASETS AND METHODS

The study is conducted on the city of London within the M25 orbital. The analyses mainly use three sets of data: employment density calculated from Census data, spatial data obtained from street network model, as well as underground network, and the data on town centres from London Plan. The main platforms and software used in this study are: QGIS (geographic information system), space syntax analysis software Depthmap, and statistical analysis software SPSS (Statistical Product and Service Solutions).
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The main source of the employment data used in this study is from the Office of National Statistics census 2011 at workplace zones level. Workplace zone (WZ) is a new type of output geography for England and Wales used in census 2011. It has been produced using the workplace data as a supplement of the Output Area (OA) level. The OAs are designed to contain consistent numbers of people, based on where they live, while Workplace Zones (WZ) are designed to contain consistent numbers of workers, based on where people work. In this study, it is the employment situation of an area that is of interest, so Workplace Zones are considered to be more suitable for producing workplace-based statistics and outputs for further analysis.

The boundary of Workplace Zones of Greater London is imported into GIS platform. With the help of the built-in Python console, the employment data of each workplace zone is joined with the geo-referenced boundary using the ID of each WZ. Each of the 8154 workplace zones contains its geographic information as well as the number of employees that work in this zone. Employment density is then calculated as follows:

Employment density (hab/km²) = Population in employment within each workplace zone/Area of that workplace zone *1000

This method generates a distribution pattern of employment density in London that can pinpoint the concentration of employment in this city. The measure is crucial for this study, and it also provides a relatively accurate method for the numerous research topics that concern spatial aspects of employment within other metropolitan cities.

Another dataset used in this research is the town centre network of London obtained from the London Plan 2015. London Plan is the overall strategic plan for London over the next 20–25 years. It sets out an overall framework that integrates economy, environment, transport and social life. Overall, 199 town centres are currently defined in the plan and are classified into four categories according to their existing roles and functions considering multiple criteria which include scale, mix of uses, financial performance and accessibility. The location of these town centres as well as their classification information are imported into GIS. In the study, the information of town centres network will serve as a reference of the current appearance of centrality of the city.

By importing all geo-referenced data into GIS, the spatial model, employment density model and town centre network model can be cross-analysed in one platform. In order to join spatial attributes of street segments with employment data of each workplace zone, each segment together with their spatial attributes are converted into its midpoint by using python console in GIS. Then these points are joined by spatial location with the workplace zones that they locate in. At the same time, the mean value of the spatial attributes, including Integration and Choice of R400, 800, 1200, 1600, 2000, 2400, 4000, 8000, 10000 and n, are calculated for each workplace zone. Through this approach, a statistic model is built, in which each workplace zone has its value of both spatial and employment data. The dataset is later imported into the SPSS software to build a linear regression model to analyse the correlation between employment density and spatial accessibility measured by Integration and Choice measurements. The same
method is applied again onto the second spatial model that contains underground network to see the difference.

3. RESULTS

3.1 EMPLOYMENT DENSITY AND TOWN CENTRES

Employment density is proposed to be a strong index of predicting centres. In the case study of London, the data of employment density is plotted onto 8154 Workplace Zones in GIS. The employment density data has a skewed characteristic. Areas with high employment density concentrate only in a small part of the city. The highest employment density areas concentrate in the main centre of London along Oxford Street. Other sub-centres of employment are dispersed radially around the centre.

By overlapping town centres with employment centres, it can be seen that employment density and the location of town centres have a strong correspondence. Due to the skewed nature of the dataset, areas with the top 40% value of employment density can be seen as employment centres. Statistically, among the 199 defined centres, 33 of them locate at the top 20% of the employment density value, and 149 of them in total locate at the top 40%, which means that 91% of the town centres are also the places where employment activities aggregate. Therefore, it can be concluded that in the city of London, the measurement of employment density is a strong predictor of centrality.

However, there are still examples of non-correspondence between the two. Some areas such as Park Royal and St George’s hospital are with high employment density but they are not serving as town centres. Most of these areas are industrial areas, large clusters of offices and factories, large hospitals, schools and government institutions that offer high number of job opportunities. In contrast, some town centres such as Harold Hill and Coller Row are found to have low employment density, and most of these centres are suburban towns located in the periphery of London and serve as local centres of their surroundings. This suggests that although employment density is seen as a strong predictor of centres, it cannot cover all conditions.

![Figure 1 - General pattern of employment density in London](image)

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3.2 SPATIAL CONFIGURATION AND TOWN CENTRES

Numerous space syntax literatures have shown how spatial configuration is related to centrality. Space syntax measure of ‘Integration’ is commonly considered as a measure that implies centrality of an area, which closely associates to the emergence of town centres (Hillier 1999). The higher the integration value is, the more central and closer is the space to all spaces within the network. It is suggested that higher spatial accessibility is associated with higher amount of pedestrian movement. The movement economies generate better economic performance of the area, thus lead to the emergence of urban centres (Hillier 1996). Here in this research, by overlapping the town centres with various spatial analyses, the correspondence between the two can be clearly seen from the pattern. Figure 2 suggests that Normalized Angular Choice Rn corresponds quite well with the location of town centres. Except for some small district centres, most of the centres lie on the highest choice value segments. Global Choice is thus indicated to be an important value for predicting centrality. Also, normalized integration in various radii can be used to identify centres of different scales. Integration Rn picks up centres in central London as well as those in the ‘wheel spokes’ (Hillier 1989) that connect the central area to the edges of the city. Integration R800 picks up centres that are locally integrated. It is able to identify those district centres that serve local communities. Besides single measures, spatial attributes in multiple scales can be combined in order to identify centres with specific features. For example, Figure 3 shows the pattern of added value of Normalized choice R800, R2400 and R8000. The pattern then can be used to identify areas that have either distinct global centrality or local centrality. In the same way, multiplied measure of normalized integration R800, R2400, R8000 can identify centres that are both locally and globally integrated (Figure4). Particular measures can be formulated according to the requirements of urban analyses.

Figure 2 - Location of town centres and global choice
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The spatial characteristics can be further studied exclusively for centres. One can establish a spatial profile of centres by creating a buffer of radius 800 metres for each centre, and joining their spatial attributes with the buffers (Figure 5). There is one exception for the centre of West End. As it covers almost the entire central area of London, a larger buffer of 2000 metres has been created for this specific case. With the spatial profile, it is easy to rank these centres according to their spatial attributes and use this as a tool to distinguish the spatial accessibility of centres and accordingly predict their socio-economic performances. As an example, Table 2 lists the top 20 centres ranked by normalized choice and normalized integration in combined radii. With the above analyses, it is evident that spatial accessibility measured by integration and choice is also a powerful tool in identifying urban centrality. It is more flexible in terms of catching centres of various scales and particular features.

Figure 5 - Buffers of centres with spatial attributes
3.3 RELATIONSHIP BETWEEN EMPLOYMENT DENSITY AND SPATIAL ACCESSIBILITY

This section explores the relationship between employment density and spatial accessibility, and how this relationship differs between centres and non-centres, and more specifically, between centres in central London and those in outer London.

Figure 6 reveals a general pattern of association between employment density and Choice values. The visual result shows clearly that, spatial accessibility centres and employment centres have a significant correspondence. To further investigate the correspondence, a statistical model is built, which includes both employment density and spatial accessibility data for all Workplace Zones. The dataset is imported into SPSS in which a linear regression analysis is carried out between employment density and spatial accessibility. In the regression model, the value of Ln (employment density+3) is defined as dependent variable while Integration and Choice value from R400 to R10000 are set as independent variables and are tested against the dependent variable respectively. Statistical analyses have proved that employment density has significant correlation with both Angular choice and Angular Integration in various radii. The overall correlation with Integration is considerably higher than that with Choice, and thus Integration measure will be used in further comparisons between models.

Table 3 records the R-squared value in each radius tested. For the entire model, the correlation is significant in all scales and has high R-squared values from 0.467 to 0.631. The highest R-squared appears at meso scales from R1200 to R4000, and is slightly lower at micro and macro scale. In terms of centres only, the correlation between employment density and Integration value is also significant, ranging from 0.416 to 0.712. There is a dramatic increase in the R-squared value of centres compared to the entire model from R400 to R2400, and it starts to decrease for larger radii. This suggests that the Integration value of micro and meso scales correlates better with employment density in centres.
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Figure 6 - General correlation between areas with high employment density and high choice value

R-squared value between Ln (employment density+3) and Integration

<table>
<thead>
<tr>
<th>Radius</th>
<th>Entire model</th>
<th>Centres</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN R400</td>
<td>0.485</td>
<td>0.712</td>
</tr>
<tr>
<td>IN R800</td>
<td>0.572</td>
<td>0.720</td>
</tr>
<tr>
<td>IN R1200</td>
<td>0.610</td>
<td>0.711</td>
</tr>
<tr>
<td>IN R1600</td>
<td>0.626</td>
<td>0.697</td>
</tr>
<tr>
<td>IN R2000</td>
<td>0.630</td>
<td>0.682</td>
</tr>
<tr>
<td>IN R2400</td>
<td>0.631</td>
<td>0.665</td>
</tr>
<tr>
<td>IN R4000</td>
<td>0.630</td>
<td>0.615</td>
</tr>
<tr>
<td>IN R8000</td>
<td>0.591</td>
<td>0.582</td>
</tr>
<tr>
<td>IN R10000</td>
<td>0.563</td>
<td>0.550</td>
</tr>
<tr>
<td>IN R</td>
<td>0.467</td>
<td>0.416</td>
</tr>
</tbody>
</table>

Table 3 - Correlations of the entire model and centres only
To further investigate this relationship, centres that located in the central London are distinguished from those in outer London. It is believed that these centres might have distinct performance than others due to their distinguished location. In this study, centres locate in central areas are separated from dataset and their spatial attributes and employment density are analysed again separately.

The results are recorded in Table 4. Statistical outputs reveal an even higher correlation between employment density and spatial integration for these centres. The increase again occurs from R400 to R2400 where the R square values reach the highest number of 0.706 to 0.824 respectively. With such results, it seems possible to suggest that the more central the areas are, the higher correlation exists between employment density and integration. In other words, the result indicates that spatial accessibility can capture better the employment agglomeration in the central areas of the city than the peripheral areas.

<table>
<thead>
<tr>
<th>Radius</th>
<th>Centres centres in central London</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN R400</td>
<td>0.712</td>
</tr>
<tr>
<td>IN R800</td>
<td>0.720</td>
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<td>IN R1200</td>
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<td>IN R1600</td>
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<td>IN R2000</td>
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<tr>
<td>IN R2400</td>
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<td>IN R4000</td>
<td>0.615</td>
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<tr>
<td>IN R8000</td>
<td>0.582</td>
</tr>
<tr>
<td>IN R10000</td>
<td>0.550</td>
</tr>
<tr>
<td>IN R</td>
<td>0.416</td>
</tr>
</tbody>
</table>

Table 4 - Correlations of all centres and centres in central London

3.4 INCORPORATING THE UNDERGROUND NETWORK AND MEASURING ITS INFLUENCE

As stated before, the underground network is considered to have its impact on the emergence of centres. In order to test such impact, a new spatial model is created in Depthmap that incorporates underground network into street network of Greater London. Lines taken into consideration include eleven London underground lines, London Overground line, Docklands Light Railway and Crossrail. All stations are geo-referenced according to London underground map from TFL. With reference to Law’s methodology of building a bi-model (Law et al. 2012), a line is drawn from each station to the street network model at about 90 degrees, which represents the cost of entering and exiting the station. Using the link function in Depthmap, each trip between stations is linked directly (Figure 7). With this method, the two independent networks are linked in one model. The new model with links between stations is then converted into axial and segment maps for analyses. The results are then imported back into GIS for further comparisons with other data. One thing to note is that the method is in its experimental stage and the optimization of the model is not the priority of this paper. Instead, a simplified way is adopted in this study to explore the trend.
With the results of the analysis for both street-only network and the combined network, it is straightforward to compare the two models and see how underground network influences the spatial configuration of the city. Figure 8 presents the global Integration value mapped on two axial maps. The upper image shows that of street-only network and the lower one the combined network. The impact is quite clear from the map. Generally speaking, in the new model, the strong central core is still maintained, but it expands along the underground network and reaches further to the periphery of the city. The central core is strengthened and enlarged due to the dense transport network in and around it. New centralities emerge in the south of river Thames, where many areas are considered to be far from central London without public transport. Another new emerging centre that can be observed in the map is to the east of the central area around Woolwich and Plumstead. The overall comparison demonstrates two main features of London underground and rail network: firstly, it covers most part of the city and brings the periphery to the centre; secondly, it generally follows the centralised structure of street network and strengthens the central core. Further comparison is made between two segment models. In order to visualize the impact, a difference map is created by calculating the difference of spatial values on each segment line of two models. Figure 9 presents the difference map of Integration R8000 between two segment models. Segments with red and yellow colours mean that their integration values are increased in the combined model, and segments with green means the value is slightly decreased. Those with grey colour stay almost the same value in two models. Firstly, it can be observed that there is great improvement in South London along the underground Circle Line, including areas such as Croydon, Penge, Forest Hill and Dulwich. Several centres in this area are largely dependent on the underground network to be linked with central London. Secondly, strong impacts are found at some transportation junctions where two or more transport lines intersect. Areas like Canary Wharf, Westham, Archway and Paddington become more integrated into the city network with the underground system.
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Figure 8 - Comparison between two axial models
The difference shown in spatial analyses gives rise to an intuitive hypothesis that in the case of London, the underground network casts influence on urban centrality. In order to test whether a hybrid spatial model including underground network can enhance its ability in predicting socio-economic performance of the city, the correlation between employment density and spatial accessibility is calculated once again in the hybrid model. Table 5 shows the results from linear regression analysis between Ln (employment density + 3) and Integration value in various radii. Comparing the entire hybrid model with the street-only model, the correlation between employment density and integration is improved in meso scale, from R800 to R2400. While at micro and macro scale it almost stays the same or even drops a bit. Results suggest that the combined spatial model can slightly enhance the prediction of employment centres in meso scale, whereas at micro and macro scale it does not make much difference. The improvement is not quite significant and only shows a trend. It is possibly because the underground network in this analysis is not weighted by the magnitude of origins and destinations for each station when being integrated into the street network model, making its influence underestimated in the results.
R-squared value between Ln (employment density+3) and Integration

<table>
<thead>
<tr>
<th>Radius</th>
<th>Entire street model</th>
<th>Entire hybrid model</th>
</tr>
</thead>
<tbody>
<tr>
<td>R400</td>
<td>0.485</td>
<td>0.485</td>
</tr>
<tr>
<td>R800</td>
<td>0.572</td>
<td>0.577</td>
</tr>
<tr>
<td>R1200</td>
<td>0.610</td>
<td>0.622</td>
</tr>
<tr>
<td>R1600</td>
<td>0.626</td>
<td>0.641</td>
</tr>
<tr>
<td>R2000</td>
<td>0.630</td>
<td>0.647</td>
</tr>
<tr>
<td>R2400</td>
<td>0.631</td>
<td>0.647</td>
</tr>
<tr>
<td>R4000</td>
<td>0.630</td>
<td>0.628</td>
</tr>
<tr>
<td>R8000</td>
<td>0.591</td>
<td>0.584</td>
</tr>
<tr>
<td>R12000</td>
<td>0.563</td>
<td>0.550</td>
</tr>
<tr>
<td>R</td>
<td>0.467</td>
<td>0.467</td>
</tr>
</tbody>
</table>

Table 5 - Compare correlation between two models

R-squared value between Ln (employment density+3) and Integration

<table>
<thead>
<tr>
<th>Radius</th>
<th>Centres street model</th>
<th>Centres hybrid model</th>
</tr>
</thead>
<tbody>
<tr>
<td>R400</td>
<td>0.712</td>
<td>0.707</td>
</tr>
<tr>
<td>R800</td>
<td>0.720</td>
<td>0.721</td>
</tr>
<tr>
<td>R1200</td>
<td>0.711</td>
<td>0.717</td>
</tr>
<tr>
<td>R1600</td>
<td>0.697</td>
<td>0.703</td>
</tr>
<tr>
<td>R2000</td>
<td>0.682</td>
<td>0.688</td>
</tr>
<tr>
<td>R2400</td>
<td>0.665</td>
<td>0.671</td>
</tr>
<tr>
<td>R4000</td>
<td>0.645</td>
<td>0.617</td>
</tr>
<tr>
<td>R8000</td>
<td>0.562</td>
<td>0.586</td>
</tr>
<tr>
<td>R12000</td>
<td>0.550</td>
<td>0.551</td>
</tr>
<tr>
<td>R</td>
<td>0.456</td>
<td>0.433</td>
</tr>
</tbody>
</table>

Table 6 - Compare the R-squared of centres in two models

However, the improvement is interestingly much more consistent when comparing the same value for only centres in two models (Table 6). Using the spatial analysis of the hybrid model, the spatial and employment data have been applied to buffers of each centre. Linear regression analysis is conducted again on centres only and the values of R-squared are recorded for each scale. Similar to the street network model, the R-squared values appear approximately between 0.5 and 0.7, which means that the space syntax measure of integration can explain more than 50% of employment density data. The comparison shows that the correlation between employment density and integration is higher in the hybrid model than street-only model. This improvement occurs in all scales except for a tiny drop in R400. It suggests that the hybrid spatial model is able to capture more accurately the employment concentration in centres than in non-centres. In other words, the impact of underground network on employment density is considered to be more significant in centres. This indicates an idea that the hybrid model that takes public transport into consideration may be a more accurate model especially in studying urban centrality.
3.5 THE HYBRID MODEL: SEARCHING FOR A STRATEGIC PLANNING TOOL USING A COMBINED MEASUREMENT OF URBAN CENTRALITY

As learned in previous sections, both employment density and spatial accessibility are strong indicators of urban centrality. To simplify, one can say that the former represents one crucial aspect of socio-economic centrality and the latter the spatial centrality. In reality, the real condition of urban centrality is complicated and has multiple facets. Although it is effective to use one set of socio-economic data or spatial model in predicting or describing centres, none of them is able to capture the full picture of urban centrality. An attempt is conducted in this section towards a more comprehensive centrality model. As proved, employment density, spatial accessibility and public transport network each has their weight in understanding and identifying urban centrality. Bearing in mind such conclusion, a new hybrid model is built for the city of London, which combines both employment and spatial data, optimised by adding transport network. This attempt implies the idea that urban centrality is not a one-fold concept. Deeper knowledge would be achieved if it can be described with multiple aspects that contribute to its emergence.

This section explores several possibilities of applying the hybrid model into identifying new classifications for centres and profiling centres based on their core characteristics.

The first stage of building a hybrid model is to put both spatial data and socio-economic data into a single platform. In this study, as each centre buffer is assigned with its spatial attributes and employment data, it is easy to identify both the correspondence and non-correspondence between the two attributes within one model. At this stage, such a model is a useful tool for describing distinct features of centres separately and accurately. It can act as a straightforward way to find out areas with non-correspondence between different aspects of centrality. Table 7 lists examples of the centres of four different categories: centres that have high values in both attributes are mainly located in the central part of London; centres that have low values in both are mainly new towns or district centres located in the periphery; centres that have high employment density but low spatial accessibility include Uxibridge, Romford and Woolwich; and centres with low employment density but highly accessibility include Palmers Green, Norbury and North Harrow. This classification offers another way of analysing centres and describing their socio-spatial performance. It provides a simple way of identifying areas with non-correspondence between spatial centrality and socio-economic centrality. And these areas are likely to have high potential for further development.

<table>
<thead>
<tr>
<th>Employment Density</th>
<th>Spatial Accessibility</th>
<th>Example of centres</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>High</td>
<td>Brick Lane, West End, Tooting</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>Uxibridge, Romford, Woolwich</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>Palmers Green, Norbury, North Harrow</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Erith, Rainham, Northwood</td>
</tr>
</tbody>
</table>

Table 7 - Examples of centres in four situations

Except for describing distinct features separately, a further step can be made by using the model to create a hybrid measure, which is able to describe the overlapping of these features. With both spatial and employment data plotted on each workplace zone, the hybrid measure can be calculated by multiplying these values. In this study, a hybrid value is calculated as below:

\[ \text{Hybrid value} = (NAIN R800+ NAIN R2400+ NAIN R10000) \times \ln(\text{employment density} + 3) \]
The map in Figure 10 presents the distribution of the hybrid value. The spatial accessibility is based on the spatial model that takes underground network into consideration. It uses the mean value of Normalized Integration R800, R2400 and R10000 to cover all scales. The areas picked up by this hybrid measure are meant to have both high employment density and high spatial accessibility in all scales. Interestingly, when the results are compared with the location of town centres defined by London Plan, almost all of these areas are classified as 'metropolitan centres', which are defined as places that serve wide catchments and have high accessibility and significant levels of employment, service and leisure functions. The only exception here is Canary Wharf. It is picked up by the hybrid measure, as the area is extremely strong in employment density value and also strong in spatial accessibility when including public transport. Although it is defined as major town centre, the performance of the area fits the description of the hybrid measure. This indicates that the current classification of centres may change as time goes by, according to the performance of the area. The hybrid model and its targeting measurement would be of help in re-classifying and multi-classifying centres with accuracy.

![Figure 10 - Centres picked by hybrid measure of employment density, spatial accessibility and underground network](image)

The examples in previous sections have primarily shown the advantages of building a hybrid centrality model for the citywide area of London. Not only does it provide a more comprehensive method of identifying centrality of the city, but it also creates a full socio-spatial profile of existing centres. In the hybrid model, each centre is given both spatial data and socio-economic data. As a result, centres can be described by either a single aspect or multiple ones. Rather than the classifications provided by London plan that define centres into metropolitan, international, major and district ones, a much more detailed and flexible classification can be offered by the hybrid model. A hybrid measurement that combines employment density, spatial accessibility and public transport network can be calculated for each centre. Table 8 illustrate the centres ranked by the hybrid measure as defined in the last section. With the measurement, a new hierarchy of these centres can be built and applied in urban planning as an important reference.
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for development decisions. In other words, the hybrid model acts as a tool to firstly, describe the performance of centres; secondly, evaluate the importance and hierarchy of centres and lastly to discover and predict the potential of them.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Name of centres</th>
<th>NAIN (R800+2x400+1x000)</th>
<th>Employment Density Ln (ED+3)</th>
<th>Hybrid Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>West End</td>
<td>4.99762753</td>
<td>47.92670978</td>
<td>3.93087536</td>
</tr>
<tr>
<td>2</td>
<td>Brick Lane</td>
<td>4.87357789</td>
<td>43.2756025</td>
<td>3.83428287</td>
</tr>
<tr>
<td>3</td>
<td>Edgeware Road / Church St</td>
<td>4.296783788</td>
<td>16.82816751</td>
<td>2.987103528</td>
</tr>
<tr>
<td>4</td>
<td>Pread St / Paddington</td>
<td>4.42402942</td>
<td>13.5405728</td>
<td>2.80589336</td>
</tr>
<tr>
<td>5</td>
<td>Angel</td>
<td>4.5908987</td>
<td>11.6054617</td>
<td>2.681367097</td>
</tr>
<tr>
<td>6</td>
<td>Knightsbridge</td>
<td>4.146570556</td>
<td>16.4348653</td>
<td>2.967068635</td>
</tr>
<tr>
<td>7</td>
<td>Canary Wharf</td>
<td>3.39078187</td>
<td>29.873896</td>
<td>3.439678922</td>
</tr>
<tr>
<td>8</td>
<td>Elephant &amp; Castle</td>
<td>4.460331833</td>
<td>9.664838127</td>
<td>2.53829502</td>
</tr>
<tr>
<td>9</td>
<td>Sheperd's Bush</td>
<td>4.18488316</td>
<td>11.60830179</td>
<td>2.68189883</td>
</tr>
<tr>
<td>10</td>
<td>Fulham Rd East</td>
<td>3.920091226</td>
<td>13.6677507</td>
<td>2.813475757</td>
</tr>
<tr>
<td>11</td>
<td>South Kensington</td>
<td>3.934120047</td>
<td>11.52137593</td>
<td>2.67560793</td>
</tr>
<tr>
<td>12</td>
<td>Camden Town</td>
<td>4.105835073</td>
<td>9.73319946</td>
<td>2.54406464</td>
</tr>
<tr>
<td>13</td>
<td>Queensway / Westbourne Grove</td>
<td>4.113583905</td>
<td>9.628452231</td>
<td>2.533952382</td>
</tr>
<tr>
<td>14</td>
<td>King’s Road East</td>
<td>3.957823706</td>
<td>10.25055724</td>
<td>2.584093608</td>
</tr>
<tr>
<td>15</td>
<td>Whitechaple</td>
<td>4.213175221</td>
<td>7.821439329</td>
<td>2.38152968</td>
</tr>
<tr>
<td>16</td>
<td>Chrisp Street</td>
<td>3.27073775</td>
<td>15.77312654</td>
<td>2.93242875</td>
</tr>
<tr>
<td>17</td>
<td>Fulham Rd West</td>
<td>4.043108561</td>
<td>7.0024105</td>
<td>2.370626269</td>
</tr>
<tr>
<td>18</td>
<td>Earls Court Road</td>
<td>3.766348297</td>
<td>9.36537886</td>
<td>2.514754883</td>
</tr>
<tr>
<td>19</td>
<td>Dalston</td>
<td>4.71636801</td>
<td>4.61931051</td>
<td>1.99622269</td>
</tr>
<tr>
<td>20</td>
<td>Kensington High Street</td>
<td>3.886312584</td>
<td>8.057984127</td>
<td>2.40352717</td>
</tr>
</tbody>
</table>

Table 8 - The top 20 centres ranked by hybrid measure

4. CONCLUSIONS

To summarize, the findings of the study suggest that both employment centrality and spatial centrality are significant indicators of urban centrality. Spatial analysis is able to supplement and enhance the understanding of centrality that is purely based on employment density, and it can be further enhanced by including public transport system into the spatial model. Therefore, a hybrid centrality model is proposed. An overall model that combines employment density, spatial accessibility and underground network is created for the city of London. It is suggested that the hybrid model is advantaged in identifying both the overlapping and non-correspondence between spatial and socio-economic centrality. It builds a full profile that can describe centres with more specific characteristics and is thus of great use in urban planning and urban decisions.

One contribution made by this research is that it provides a methodology for applying census data in large scales to spatial studies with a satisfactory level of accuracy. In the situation where detailed social-economic data are sparse and incomplete, it is an efficient approach to use census data and spatial analysis to evaluate the pattern of centrality. This research has used a method that joins spatial data with socio-economic data based on census boundary, by simplifying street segments into points that carry with all spatial attributes and calculating the
mean values of the spatial attributes for all points that fall in the boundary of each workplace zone. This methodology manages to take advantage of the vast range of census data on a relatively detailed level. The output offers a feasible way to relate spatial analysis with many other aggregated data and is especially useful in urban-scale studies.

Another virtue of this research is that it provides in-depth analyses on centralities identified by multiple aspects. The study has shown that through building a hybrid centrality model, a better understanding of urban centrality and the performance of centres can be obtained. The hybrid model provides a measurement that constitutes considerations on spatial accessibility, employment density and public transport. The measurement should be considered as a starting point for viewing centrality from multiple aspects. In the era of Big Data, spatial configuration models, census data and many other socio-economic data are easier to obtain and should be properly exploited. It is important to note that this study is not trying to imply that always the maximum level of information should be considered in the model. It is more about suggesting that, when needed, a more comprehensive model of centrality could be built with consideration of the aspects that are important and can enhance the final output. The value of the hybrid model does not lie in adding yet another measurement, but in applying space syntax analysis into a broader context, where multiple actors can work interdependently in one model, just as it is done in real urban systems. Such a model is proposed to be more clarifying and more useful for future urban planning and urban economic studies as, well as a tool for strategic and investment decision-making.
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COMBINING INTEGRATION WITH WALKING CONDITIONS IN URBAN ROUTES:
Development of a test model

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ABSTRACT
Walking conditioning urban characteristics, hereafter just denominated walking constraints, consist of characteristics of natural and built environment that are inherently relevant to pedestrian routing decision making (e.g., stairs, street crossings, and slopes). Beyond these constraints, space syntax provides high level spatial metrics, such as integration, which has been related to pedestrian motivations (Penn et al., 1998; Lerman et al., 2014; Koohsari et al., 2016), and so may contribute to improve current route generation. We believe much can be done concerning route generation in order to promote walking, especially through improvement on underlying geographical data, and on adaption to pedestrian motivations. Space syntax findings concerning pedestrian motivations should start to be considered in the latter improvement point.

With the previous preamble in mind, we have developed a model for a routing tool that supports (1) parameterization based on walking constraints and integration, (2) generation of alternative routes, and (3) comparison of alternative routes in terms of time, energy expenditure, and integration. We report here the development and implementation of that model, including (1) gathering and processing data using a GIS software (pedestrian footpaths and crossings, digital terrain model, walking speed and physical effort, footpath shading, and integration measurements), and (2) generating the pedestrian routes. We show the model in action in two case studies for two areas in the city of Lisbon, and compare results with well-known route generation tools (route generators).

KEYWORDS
Active Living, Healthy City, Pedestrian Route Generation, Urban Walking Conditions
1. INTRODUCTION

Current route generators already provide help for pedestrians regarding time estimating and rudimentary route finding, similarly to what is offered for car travelling. However, much needs to be done in order to take full potential of urban georeferenced data and to provide proper help for using the city by walking. Taking the example of cars, the introduction of traffic information was a recent improvement in route planning. However, in the case of pedestrians’ route planning, routes matter more than just the time to be travelled. Each person has varying personal motivations and physical conditions, paths include different walking constraints, and there are more or less dynamic walking influencing factors related to weather and land use. As a contribute in this direction, the model we bring here considers walking constraints, sun exposition, and integration.

Our model has a main geographical data layer corresponding to a network of segments, where each of these represent a path part with a set of attributes, such as slope, speed, length, shading, and integration values. The model allows time, oxygen consumption, and energy expenditure calculations and generates pedestrian routes according to any of these attributes and results. Most of this information can also added as map layers.

We divide the rest of the paper in four sections. The following section contains the theoretical background, with important concepts and previous works encountered on route generation and related areas. Afterwards, we explain the model and its construction in the third section. In the fourth section we present two case studies that demonstrate the functionality of the model. Finally, we make some considerations about the success here reported in using the last development stage of our model (which includes the use of integration), and the motivation for improving it in the future.

2. BACKGROUND

Active design aims for principles of intervention at city scale that promote health-related physical activity through non-intrusive and intuitive solutions. For instance, focusing on daily walking routines and active transportation (Badland and Schofield, 2005; Sallis et al., 2004). Gomez et al. (2010) analysed various districts and their socio-economic status, slopes, proximity to the transport system and the percentage of area dedicated to public parks. Among other findings, a negative relationship between slopes higher than 4% and regular physical activity was found. Slope corresponds to a walking constraint that should be considered by route generators.

There are several route generators that offer directions for walkers who want to take a trip from one specific location to another (Bing Maps, 2015; Google Maps, 2017; OpenRouteService, 2015; OpenStreetMap, 2015; Wheelchair routing, 2015; Yahoo Maps, 2015). However, these applications, besides leaving out walking constraints, such as slopes, miss footpaths that can be hiked, like parks and gardens. The quality of geographical data used in these applications is crucial for the adequacy of routes. However, this data is typically based on motorized and not on pedestrian travel. It has been detected that this limitation translates into very different results in various kinds of analysis (Chin et al., 2008). Notably, WheelchairRouting (2015) is an application that provides accessible paths for wheelchair users by identifying obstacles and showing the slopes.

KESUE project developed a network model, going from one model based on roads’ centre lines to a model based on sidewalks, crosswalks and all existing footpaths in the studied region (Ellis et al., 2013). In another work (Gonçalves et al., 2015), rules were created for digitizing all footpaths, including informal pedestrian crossing, thus helping to streamline and standardize the creation process of network models. This work also developed an evaluation procedure for walkability, i.e. the measure or ability to perform pedestrian travel (McCormack and Shiell, 2012), using the slopes and a quantitative and qualitative assessment of the constraints of the footpaths. Frank et al. (2005) used pedometers to measure physical activity and have positively related the results to several urban metrics, which were translated into a walkability index.
A route generator has to consider reference values of walking speed. For instance, we use Tobler’s hiking equation (1), which receives the slope angle $S$ (in degrees) and returns the speed $W$ (in km/h) (Tobler, 1993). In this case, no slope will correspond to a speed of 1.4 m/s.

$$W = 6e^{(-3.5|S+0.05|)}$$

More authors have worked on determining reference walking speed. Fruin (1987) considers an average walking speed of 1.36 m/s. This author further mentions that speed on stairs depends on the dimensions of the risers and treads, that the average speed of climbing is about one third of walking speed without any slope, and that down stairs speed increases by 10%.

Considering reference walking speed in road crossing, Faria et al. (2010), who compared short urban travels in several means of transportation, also included pedestrian, and measured several waiting times for signalized pedestrian crossings, zebra pedestrian crossings and informal crossings. They concluded that a unique waiting time of 10.9 seconds should be used in any signalized crossing, and zero seconds in zebra and informal crossings; without mentioning the walking starting time or the time used to check crossing’s safety. The Transportation Research Board (2000) considers that a starting time of three seconds is reasonable to calculate pedestrian crossing. For this purpose, we also found that local authorities do not store the green and waiting times for the signalized crossings and that the majority of these times are dynamic.

The best found estimates of energy expenditure need data that our model does not have. Yamazaki et al. (2009) developed equations that calculate energy expenditure based on accumulated acceleration, which allow to estimate values very close to those obtained experimentally, and published a table with measurements for energy expenditure and oxygen consumption, combining different values of speed (rest, slow, moderate, fast and very fast) and slope (positive and negative), which we have used.

It is possible to estimate the oxygen consumption, which allows the calculation of calorie expenditure (American College of Sports Medicine, 2013), in terms of speed, slope, or both. Several equations and the corresponding graphs were evaluated before the choice of the equation to be used in the model (Luta, 2016). This equation was estimated (with interpolation) using the mentioned findings of Yamazaki et al. (2009).

3. MODEL

This section is divided in three subsections: (1) building - describing how the model was created, (2) measuring and using – showing the first layer of model data and explaining how the model can be used to generate routes, and (3) testing – reporting how a set of tests were carried out.

3.1 BUILDING

Having access to a previously developed model of a pedestrian travel network (Gonçalves et al., 2015), we started from it and added several characterization aspects to the already digitized footpaths using a GIS application. For each segment, the walking speed was calculated according to the slope, using Tobler’s equation. Additionally, the speed for walking up and down stairs was calculated following Fruin’s work.

The slope of each segment is calculated using only the start and ending points, so we divided it into smaller segments looking for the right granularity for the network. To identify the elevation of each segment of the network, which was necessary to calculate the slope and walking speed, a Digital Terrain Model (DTM) was necessary. If it had insufficient spatial resolution it could result in too many small segments with no slope. Additionally, segments too close to the DTM’s cell limits could end up with an incorrect slope. At the end, a new DTM was created with one meter resolution, 100 times bigger than the initially available DTM.

Accordingly with previously related works, we considered that the pedestrian stops at the beginning of each informal and zebra crossing, resuming the march immediately with no waiting time, being only considered the starting time of three seconds according to the best references found.
Almost all the signalized intersections in Lisbon have some degree of dynamic adaptation of the green time, and therefore both the average green time for every crosswalk and the temporal relationship between them are unknown. Several crossings are divided in segments and as a result it is not possible to know which pedestrian walking speeds allow the crossing of a given number of segments in one go. Therefore, we are unable to identify the situations where there may exist several stops on a crossing. Without a correct way to characterize the signalized crosswalks, these were treated as the remaining crossings – three-second penalty, the pedestrian start time.

Another option included in the model is the choice of routes depending on the shade of footpaths. To be able to identify footpaths exposed to the sun or the shade it was first necessary to create the volumes that represent the shading of the buildings. These buildings were modelled using the map data used in the DTM creation. Due to the nature of this data, the model ignores walls and simplifies the buildings, not including archways and cantilevered elements. Because of their inherent complexity the plants and street furniture elements were ignored. To represent summer and winter, the hottest day and the coldest day recorded for the city of Lisbon were chosen, respectively, which are the extreme days to consider the motivation for each criteria – avoiding shaded or in the Sun footpaths. The winter shading volumes were created for five moments of the day: 9h00, 11h00, 13h00, 15h00 and 17h00. For summer six volumes were created, being represented in addition the 19h00 moment. Being created the various representative volumes of shading, the footpaths were identified as fully shaded, partially shaded or not shaded.

To add integration to the model, axial lines were used in DepthMap to create a segment analysis which used the following radius: n, 1200m, 800m and 400m. The segments and its values were imported into the GIS application and were associated with the built pedestrian networks using angle and distance spatial relations. For comparisons between paths these values were weighted with the length of each segment. The route creation is solved by the Dijkstra’s algorithm through the ArcGIS software. To enable using integration as an impedance cost, these values were inversed, weighted and stored in new fields.

In order to generate the pedestrian routes (PR) it’s necessary to create the network database. The various footpaths were added and from its stored values the model impedance costs were selected and created. In this model a PR may be generated according to distance, oxygen consumption, time ignoring slopes, time considering the slopes, time considering the slopes and stairs or integration. Any value that is not used as the impedance cost can be calculated and stored. This allows knowing the oxygen consumption in a PR generated according to time, for example. Other fields were also added to the model as restrictions and descriptors. These identify the footpaths as stairs, their slope and their shade state for every modeled moment. Finally, with the footpaths identified as pedestrian crossings, midpoints for each were created and added to the model as added cost points.

3.2 MEASURING AND USING

After being fully characterized, the pedestrian network had a segment average length of 7.79 meters with a standard deviation of 2.52 meters, in a total of 21393 segments which together measure 166693 meters. For each calculated field we stored two values, one in each direction of the footpath. Therefore it is possible to calculate all results in both directions, which is essential to identify the effect of slopes in pedestrian walking.

The network of footpaths has an average slope of its segments of 4.60%. Given that the various segments that compose this network have different lengths, performing a weighted average gave the average slope of the network: 4.53%. In figure 1 is visible the full pedestrian network with the footpaths spread over different slope ranges. In table 1 the number of segments, the total length of footpaths and the percentages for each slope range are visible. An interesting fact to take from this table is that 83.4% of the study area has slopes under 8%, a figure relevant to the study of some user groups with reduced mobility.
COMBINING INTEGRATION WITH WALKING CONDITIONS IN URBAN ROUTES:
Development of a test model

Figure 1 - Footpaths’ slope [%]

<table>
<thead>
<tr>
<th>Slope [%]</th>
<th>Number of segments</th>
<th>Length [m]</th>
<th>%</th>
<th>Accumulated %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>7627</td>
<td>59580</td>
<td>36%</td>
<td>36%</td>
</tr>
<tr>
<td>2-4</td>
<td>4821</td>
<td>37861</td>
<td>23%</td>
<td>58%</td>
</tr>
<tr>
<td>4-6</td>
<td>3157</td>
<td>24720</td>
<td>15%</td>
<td>73%</td>
</tr>
<tr>
<td>6-8</td>
<td>2105</td>
<td>16835</td>
<td>10%</td>
<td>83%</td>
</tr>
<tr>
<td>8-10</td>
<td>1311</td>
<td>10252</td>
<td>6%</td>
<td>90%</td>
</tr>
<tr>
<td>10-12</td>
<td>852</td>
<td>6499</td>
<td>4%</td>
<td>93%</td>
</tr>
<tr>
<td>12-15</td>
<td>652</td>
<td>4846</td>
<td>3%</td>
<td>96%</td>
</tr>
<tr>
<td>15-20</td>
<td>422</td>
<td>3073</td>
<td>2%</td>
<td>98%</td>
</tr>
<tr>
<td>20-30</td>
<td>186</td>
<td>1219</td>
<td>1%</td>
<td>99%</td>
</tr>
<tr>
<td>&gt;30</td>
<td>34</td>
<td>218</td>
<td>0%</td>
<td>99%</td>
</tr>
<tr>
<td>Stairs</td>
<td>226</td>
<td>1590</td>
<td>1%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 1 - Footpaths’ slope
Knowing if the footpaths are shaded allowed us to create another analysis of the network. As mentioned above, the partially and fully shaded footpaths were identified. Partially shaded footpaths were all treated the same, not being detailed the percentage of shade and sun. The study area with modelled shading is limited to the north by Avenida Elias Garcia and Avenida António José de Almeida, to the west by Rua Marquês Sá da Bandeira, to the south by Rua Tomás Ribeiro, Rua Almirante Barroso and Rua Pascoal de Melo, and the east by the Avenida Almirante Reis. It has 6120 segments which together measure 49017 meters. The segments have an average slope of 3.09% and the network 3.14%. In table 2 the length and percentage of fully shaded, partially shaded or not shaded footpaths for the several modelled moments are shown.

| Time | Fully Shaded | | | | Partially Shaded | | | | In the Sun | | |
|------|--------------|------|------|------|------------------|------|------|------|------------------|------|------|------|
|      | Length [m]   | %    | Length [m] | %    | Length [m] | %    | Length [m] | %    |
| Winter | | | | | | | | | | | |
| 09h | 9520 | 19% | 35888 | 73% | 3609 | 7% |
| 11h | 29024 | 59% | 7630 | 16% | 12363 | 25% |
| 13h | 23559 | 48% | 9526 | 19% | 15933 | 33% |
| 15h | 32911 | 67% | 6837 | 14% | 9269 | 19% |
| 17h | 46756 | 95% | 1125 | 2% | 1127 | 2% |
| Summer | | | | | | | | | | | |
| 09h | 23997 | 49% | 8692 | 18% | 16328 | 33% |
| 11h | 15644 | 32% | 8044 | 16% | 25330 | 52% |
| 13h | 9498 | 19% | 8369 | 17% | 31151 | 64% |
| 15h | 11601 | 24% | 7144 | 15% | 30272 | 62% |
| 17h | 15675 | 32% | 8754 | 18% | 24588 | 50% |
| 19h | 30266 | 62% | 7581 | 15% | 11171 | 23% |

Table 2 - Shaded footpaths

In order to generate routes, at least two locations must be added, representing the starting point and destination. One of the created impedance costs must be selected to generate the route, the remaining ones can be selected as accumulation attributes which help characterize the route: length, time ignoring slope effect, time with slope effect, time with slope and stairs effects, oxygen consumption (and therefore calories consumption), weighted integration and inversed weighted integration.

In addition, any combination of the restrictions can be used as prohibited, avoided or preferred, further specifying the degree in which they are avoided or preferred: stairs, informal pedestrian crossings, slopes (choosing the breakpoint), Sun and shading (from any of the modeled moments). To remove or add the penalty for each pedestrian crossing, the added cost points need to be removed or added, respectively.

Being implemented in ArcGIS, each model generated route can be saved and stored with all resulting values.

3.3 TESTING

Three different sets of tests were carried out as a proof of concept of how the model should be validated in the future.

For several routes the final walking time (considering slope and stair effects and adding pedestrian crossing’s penalties) was compared with Google Maps’ (2017) walking time. From
all routes generated in the case studies showed in the results section, 20 unique ones were identified and recreated in Google Maps (2017), using when necessary additional destinations to force the route's geometry. Five routes were unable to be reproduced because of the absence of Av. Praia da Vitória at the time. With a sample of 15 routes the average difference between the model and Google Maps (2017) is 3.55 or 3.89% with a standard deviation of 2.45 or 2.23%.

The model’s energy consumption results were compared with the results of two different commercial solutions, Samsung Gear Fit smartwatch and MapMyWalk (2017) fitness tracking application. Eight different routes (four in both directions) were measured 22 times with either solution. The tracking application often had discrepant results which were not used whenever the route was measured having more than 20% of its supposed length. In the end 15 measurements were used and compared giving an average difference of 8 kcal or 13.29% and a standard deviation of 8 kcal or 12.54%.

To compare the shading measures no other model or application was found, and therefore the model results were compared on site. For this purpose, the shading was modeled for five moments of a new day: 10h00, 12h00, 14h00, 16h00 and 18h00. A 30 min route starting at 15 min before each of the five moments visited 14 locations (selected with the goal of having different street directions and width), and in each one the shading was compared to what was expected in the model for that specific day. From the 70 locations, 14 were unable to be compared due to bad weather conditions, 12 had to be compared from predicting the shading by watching the Sun position behind the clouds and 44 were easily compared. The results were mostly positive with 54 locations having in the Sun or shaded pedestrian paths similar to the model results, and only two locations where the same cannot be said. In the latter both sides of the street were expected to be in the Sun but were not, this can easily be explained by a combination of three factors: the pedestrian travel network used as base for the model was previously developed and didn’t specify the distance between the segments that represent the sidewalks and the buildings; the time period where a street with high buildings has both sidewalks without any considerable shading is short and can easily be missed; and the used software doesn’t specify how it adjusts for Daylight Savings Time.

4. RESULTS

The first case study has routes between one of the entrances of the Alameda subway station and the Civil Pavilion entrance at Instituto Superior Técnico (IST).

The first route was created ignoring slope effect on walking speed. The second route considered the slope effect, and the third route considered slope and stair effects. To calculate the fourth route, pedestrian crossings were added, with the correspondent time penalty, on top of the effects for the third route. This is the first route using all effects and all following routes in the case studies will only consider these complete application. The previous (building up) routes provide some insights about the incremental use of these effects.

To demonstrate other slope consequences, first a route was created in which the starting point and destination are reversed, and second, routes where stairs are prohibited and slopes higher than 8% are penalized - with moderate penalties (value 2) and with high penalties (value 5). If instead of adding penalties these slopes are prohibited the model cannot find a route. If instead, slopes higher than 9% are prohibited a solution is found. The table 3 and figure 2 summarize these routes. For each one is shown, not only the distance and time, but also the oxygen and energy expenditure calculated by the model.
COMBINING INTEGRATION WITH WALKING CONDITIONS IN URBAN ROUTES: Development of a test model

Figure 2 - Pedestrian routes between Alameda and IST

<table>
<thead>
<tr>
<th>Route</th>
<th>Description</th>
<th>Length [m]</th>
<th>Time [s]</th>
<th>VO2 [ml/kg]</th>
<th>Energy [kcal]</th>
<th>Figure (Route)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alameda - IST</td>
<td>Ignoring slopes</td>
<td>658</td>
<td>470</td>
<td>--</td>
<td>--</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Alameda - IST</td>
<td>Factoring slopes</td>
<td>658</td>
<td>575</td>
<td>154</td>
<td>54</td>
<td>2 (1)</td>
</tr>
<tr>
<td>Alameda - IST</td>
<td>Factoring slopes and stairs</td>
<td>700</td>
<td>595</td>
<td>153</td>
<td>54</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Alameda - IST</td>
<td>Factoring slopes, stairs and crossings (SSC)</td>
<td>700</td>
<td>610</td>
<td>153</td>
<td>54</td>
<td>2 (2)</td>
</tr>
<tr>
<td>IST - Alameda</td>
<td>Factoring slopes, stairs and crossings (SSC)</td>
<td>700</td>
<td>486</td>
<td>111</td>
<td>39</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Alameda - IST</td>
<td>SSC - No stairs, avoid: medium slopes higher than 8</td>
<td>700</td>
<td>610</td>
<td>153</td>
<td>54</td>
<td>2 (2)</td>
</tr>
<tr>
<td>Alameda - IST</td>
<td>SSC - No stairs, avoid: high slopes higher than 8</td>
<td>876</td>
<td>738</td>
<td>186</td>
<td>65</td>
<td>2 (3)</td>
</tr>
<tr>
<td>Alameda - IST</td>
<td>SSC - No stairs, prohibited slopes higher than 9</td>
<td>1326</td>
<td>1053</td>
<td>269</td>
<td>94</td>
<td>2 (4)</td>
</tr>
</tbody>
</table>

Table 3. Pedestrian routes between Alameda and IST

The fastest route created by Google Maps (2017) is not given as a solution in our model. This route uses informal pedestrian crossings which are not modeled, since not only they would be too close to existing pedestrian crossings, but can also be considered dangerous. Google Maps’ second fastest route created has the same geometry, distance and time as the fourth route created by our model. Both can be seen in figure 3, in blue the former and in grey the latter.
In the second case study, several routes were created - between Avenida Conde Valbom and Jardim Cesário Verde - using as restrictions the Sun and shading of the several modeled moments described in the previous chapter. In addition to the metrics shown in the first case study, the integration is also shown. The first route (figure 4) is created considering the slope, stair, and pedestrian crossings effects and is used to benchmark the remaining routes. This route has the same length and time as the solution given by Google Maps (2017): 15min and 1.2km. The 1200m value for the integration radius is chosen due to its proximity to the length of this route. Each route’s integration is calculated as a weighted average of integrations of all included footpaths.
For summer routes the footpaths with no shade were moderately avoided having a value of penalty 2, meaning that each footpath was accounted with a double impedance cost - but the returned costs are correct. The footpaths partially shaded have a lighter penalty valued 1.3 and the fully shaded paths are not penalized. In winter routes this logic is reversed, and the fully shaded footpaths are penalized. To simulate situations where the Sun in summer, and the shade in winter want to be avoided at higher costs, some routes were created with penalties increase - from 1.3 to 2 and 2 to 5, respectively. Figures 5 and 6 show routes in winter and figures 7 to 9 routes in summer, in each figure the pedestrian paths are coloured according to its shading properties.

Figure 5 - Pedestrian routes for Winter 09h

Figure 6 - Pedestrian route for Winter 15h
Figure 7 - Pedestrian route for Summer 09h

Figure 8 - Pedestrian route for Summer 13h
The integration was used to generate routes (figure 10). The table 4 summarizes all routes for this case study. In this table, we can notice that the higher integrated route does not correspond to the highest value in the average integration column. To create this route the algorithm finds the lowest total cost route using the selected impedance - the weighted inverted integration value (WII) – and not the lowest average cost. For the lower integrated route the weighted integration value is used.
<table>
<thead>
<tr>
<th>Starting point</th>
<th>Description</th>
<th>Length</th>
<th>Time</th>
<th>VO2</th>
<th>Energy</th>
<th>Average Integration</th>
<th>WII</th>
<th>Figure (Route)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. Conde Valbom</td>
<td>SSC</td>
<td>1185</td>
<td>896</td>
<td>219</td>
<td>76</td>
<td>397</td>
<td>3.12</td>
<td>4</td>
</tr>
<tr>
<td>Jardim Cesário Verde</td>
<td>SSC</td>
<td>1185</td>
<td>909</td>
<td>223</td>
<td>78</td>
<td>397</td>
<td>3.12</td>
<td>4</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Winter 09h</td>
<td>1213</td>
<td>914</td>
<td>224</td>
<td>78</td>
<td>396</td>
<td>3.20</td>
<td>5 (1)</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Winter 09h - Higher penalties</td>
<td>1312</td>
<td>1008</td>
<td>243</td>
<td>85</td>
<td>362</td>
<td>3.70</td>
<td>5 (2)</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Winter 11h</td>
<td>1232</td>
<td>946</td>
<td>228</td>
<td>80</td>
<td>363</td>
<td>3.49</td>
<td>--</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Winter 13h</td>
<td>1205</td>
<td>920</td>
<td>222</td>
<td>78</td>
<td>370</td>
<td>3.34</td>
<td>--</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Winter 15h</td>
<td>1295</td>
<td>984</td>
<td>241</td>
<td>84</td>
<td>383</td>
<td>3.42</td>
<td>6</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Winter 17h</td>
<td>1185</td>
<td>896</td>
<td>219</td>
<td>76</td>
<td>397</td>
<td>3.12</td>
<td>--</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Summer 09h</td>
<td>1303</td>
<td>990</td>
<td>242</td>
<td>85</td>
<td>378</td>
<td>3.50</td>
<td>7</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Summer 11h</td>
<td>1229</td>
<td>930</td>
<td>228</td>
<td>80</td>
<td>385</td>
<td>3.33</td>
<td>--</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Summer 13h</td>
<td>1242</td>
<td>934</td>
<td>229</td>
<td>80</td>
<td>404</td>
<td>3.17</td>
<td>8</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Summer 15h</td>
<td>1223</td>
<td>927</td>
<td>225</td>
<td>79</td>
<td>396</td>
<td>3.17</td>
<td>--</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Summer 17h</td>
<td>1217</td>
<td>917</td>
<td>225</td>
<td>79</td>
<td>395</td>
<td>3.22</td>
<td>--</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Summer 19h</td>
<td>1235</td>
<td>942</td>
<td>228</td>
<td>80</td>
<td>375</td>
<td>3.40</td>
<td>9</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Most Integrated</td>
<td>1214</td>
<td>941</td>
<td>224</td>
<td>78</td>
<td>402</td>
<td>3.08</td>
<td>10 (1)</td>
</tr>
<tr>
<td>Av. Conde Valbom</td>
<td>Least Integrated</td>
<td>1265</td>
<td>1009</td>
<td>232</td>
<td>81</td>
<td>338</td>
<td>3.85</td>
<td>10 (2)</td>
</tr>
</tbody>
</table>

Table 4 - Pedestrian routes between Avenida Conde Valbom and Jardim Cesário Verde
5. CONCLUSIONS

The main achievement of this work is the use of integration in a route generation process. Our model aims the generation and comparison of routes, providing also the parameterization of the generation process, as well as the comparison of the generated alternative routes. Previously to this work, we have included footpaths’ slopes, stairs, pedestrian crossings, and shading as variables of parameterization; including also time, distance and physical effort as variables for the comparison. Now, with the work here reported, we are convinced that integration may improve models such as ours in every stage: parameterization, generation and comparison of routes. In the studied cases, new routes were achieved meeting integration based metrics, validating the ability of the model to adapt to new pedestrian motivations.

The presence of shaded and non-shaded footpaths and its use brought relevant results allowing the users to choose either type of footpaths and encourages the continuation of its development. The signalized crosswalks’ characterization should be further developed since they were treated like the remaining crosswalks and may be missing relevant and useful characterization.

Energy expenditure is a crucial metric to inform the pedestrian movements in this research and related areas. It will be important in works like ours to keep up with necessary improvements on results about calculating this metrics based on walking speed and slope. Likewise, space syntax measurements depend on the adequateness and completeness of underlying data, therefore also improvement of quality of geographical data is necessary. We only explored starting ideas and surely integration values can be used in additional and different ways in the route creation algorithm, identifying and testing them should be considered as future work.
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Yahoo Maps (2015), Web-based service.
MODELLELING BIKEABILITY;
Space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg

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ABSTRACT
For numerous reasons related to energy demand, emissions, public health as well as liveable and attractive cities, a frequently stated aim in contemporary discussions on urban development is to increase amount and modal share of bicycling. In recent years, space syntax based methods have shown to be useful for providing informed premises for these discussions. Combining space syntax analyses with data on locations of residents, workplaces and destinations opens the door not only for predictive modelling of route choice preferences but also the potential amount of bicycling along routes. Building on previous research, the research presented in this paper develops space syntax based measures expected to capture bicycling and evaluates these measures by comparing the analyses with empirical data from studies carried out in cooperation with the City of Gothenburg. Among the variables considered essential for bicycling and included in our GIS model are: the slope and curvature of routes, the width and surface type of bicycle lanes and the kind and amount of traffic along the route. For modelling bicycling flow potentials, a measure termed Origin-Destination Betweenness (OD-betweenness) is used and tested, examining different combinations of variables and threshold distances.

The empirical data consists of gate counts of bicycle traffic and detailed GPS-tracks mapping actual bicycling speeds of ca. 900 trips along a selection of bicycle routes. Using multiple regression analysis to model speed data, eight variables were found significant. In addition to slope and curvature of routes, the significant variables relate to proximity to traffic signals, degree of separation from pedestrians, density of entrances along the routes and quality of paving of the cycle lane.
Concerning bicycling flow potentials, the most significant variables in the multiple regression model were: OD-betweenness within 5 km, segment angular integration within 10 km, density of residents and people at work (students included) within 1 km and network betweenness within 3km.

Based on the results of the current project, a proposal for further research is to elaborate on the OD-betweenness analyses by including speeds and preferably traffic safety in the betweenness measure. By using time along segments instead of metric length for defining the analysis threshold (radius), it should be possible to have a new and improved generation of space syntax based accessibility analyses for bicycling studies. A working name for such a measure is "least impedance origin destination betweenness".

KEYWORDS

Keywords: Bikeability, Bicycle Routes, Bicycle Speeds, Origin Destination Betweenness

1. INTRODUCTION

Among traffic engineers as well as urban planners and architects there is an increasing awareness of the positive effects of bicycling and the need to include it in planning and design of the built environment. From personal experiences, bicyclists know that route choice as well as speed are strongly influenced by the character of the terrain, by mode and amount of traffic on route, and by type and quality of the streets, lanes and paths that together constitute the route network for bicycling. Nevertheless, most contemporary urban and traffic planning practice handles bicycling only schematically. Typically, current tools for analysing bicycling rely on templates based on fixed speeds, paying little attention to variations in the type of bicyclist or explicit properties of bicycle routes and their context. Concerning amounts of bicycling, such as modal share of daily commuting on bicycle or numbers of bicyclists on specific routes, current policy and planning is often based on assumptions of a general percentage increase over the entire bicycle network, regardless of route location within this network and particular properties of those routes (Nilsson, 2013). As long as these simplified assumptions form the basis for analysis, it will be hard to make reliable comparisons of alternative proposals for bicycle infrastructure investments, for instance by means of cost and benefit analyses. Current transport modelling tools typically include numerous variables for transportation demand, distance measurements and route capacities, but scarcely take into account urban form variables related to the cognitive ease of route finding or the directness and smoothness of routes, variables that have proven to be essential for bikeability of the built environment (de Groot, 2007). In general, analyses that do not explicitly include urban form variables provide little support to urban planning and design in relation to bikeability. Therefore, from the perspective of traffic planning as well as from the perspective of urban planning and design, it would be useful to have more refined and user friendly methods for predicting speed and amount of bicycling.

In previous space syntax based modelling of bikeability at the neighbourhood scale, metric distance has been the standard measure for grasping peoples’ preferences for convenient travel (Manum and Voisin, 2010; Manum and Nordstrom, 2013; 2015). However, due to the wide range of possible travel speeds, type and quantity of daily commuting depends much more on travel-time than on metric travel-distance. By measuring only metric distances, previous models do not take the influence of different bicycling speeds into account; speeds that vary a lot depending on type of bicycle and bicyclist as well as on numerous features of the built environment. Hence, improved modelling of bikeability requires improved knowledge about the variation in bicycling speeds and how the built environment influences this. According to transportation research, speed along the bicycle network is also important regarding bicyclists’ route choices (Broach, Dill and Gliebe, 2012). Therefore, understanding and measuring bicycle speed potential is a basis for understanding bicycle flow potentials. Besides being useful for design of bicycle routes and related issues of urban form, improved estimations of bicycling speeds and bicycling flows should also be applicable to traditional transport models, since transport quantities and travel times for different transport modes are basic issues in analysing transport mode choices.
The aim of this research project has been to contribute to developing methods for modelling bikeability of the built environment. More explicitly, the aim has been twofold. First, for a better understanding of how street properties affect speeds, to develop an empirically based model for estimating bicycle speeds in inner city environment. Second, for understanding how urban structure, in terms of spatial configuration and density and a combination of the two, influences bicycle flows: to examine the relationship between aggregated bicycle flows and a set of space syntax based measures.

2. BACKGROUND

2.1 SPACE SYNTAX MODELS VERSUS TRAFFIC MODELS

Motorised travel is a highly technological and regulated activity, where the individual interacts with the environment mediated by the vehicle and the technical mobility infrastructure following strict sets of rules. Walking and bicycling, on the other hand, are shorter and slower travel modes, sensitive to environmental conditions and closely interacting with the urban context. This kind of interaction between built form and movements of people is a field where space syntax models have proven to be highly useful.

Differently from typical traffic models, the object of analysis in space syntax models is the built environment rather than mobility flows. This does not imply that space syntax models are representations of the physical environment. Rather that they are representations of what is called affordances (Gibson, 1986), that is, what a given environment affords (i.e., presents potentials for) a certain ability in an agent (Gibson, 1986: 127). Hence, they do not model either the physical environment or human activity, but what emerges in the meeting between properties of the physical environment and both physical and cognitive human abilities (Marcus, 2015). This is of principal interest to both urban and traffic modelling, since it presents a way forward in overcoming the subject-object dichotomy often found at the foundations of both urban and traffic modelling. We may, for instance, imagine models extending the space syntax approach to different traffic modes, where the built environment offers particular affordances for different vehicle types, creating what has been called modality affordances for the different locations within an urban landscape (Gil, 2016). Finally, there is reason to stress that current space syntax-models, in comparison to most models of cities as complex systems (e.g. Batty, 2013), are static in that they do not include a time variable. They are not predictive simulations, but rather descriptive models preparing for analysis. One may say that by modelling structure as affordances in the manner described above, they in a sense do capture process, that is, the potential for particular human activities created by a set of affordances, but they do not capture process where these affordances in themselves change over time.

2.2 SPACE SYNTAX BASED STUDIES ON BIKEABILITY

With the development of space syntax theory, measures and software, space syntax analyses have proven useful for modelling the bikeability of street networks (McCahill and Garrick, 2008). There have been two major space syntax developments in this respect. One is angular segment analysis, measuring network distance by taking into account the angles between intersecting street segments (also termed angular distance or angular depth). This is different from measuring network distance as topological steps of lines being either connected or not, as is the case in traditional space syntax axial analysis (Turner, 2001; 2005; 2007; Hillier and Iida, 2005; Hillier et al., 2012). The other is the development of software combing space syntax and GIS, such as the Place Syntax Tool (Ståhle et al., 2005). Raford et al. (2007) examined bicycling in London by means of shortest routes, space syntax integration using angular depth and other spatial configuration measures, and found “angular minimisation” to be essential for bicyclists’ route choice, particularly for bicycle flow potentials at aggregated level.

The other development emerges from bicycling studies in the cities Trondheim and Oslo. These studies combined space syntax choice and integration measures within metric distance thresholds (radii) with the analysis of locations of residents, workplaces and other destinations.
at individual address-points applying the Place Syntax Tool. One result was that high values of street network integration around workplaces was significant for modal share of bicycling, while integration around home locations was not (Manum and Voisin, 2010). Furthermore, the studies of Trondheim showed convincing correspondence between bicyclists’ route choice (as found in the empiric study) and segment angular choice with a metric radius. These analyses have proven useful for understanding bicycle potential of the existing bicycle route network and for illustrating the likely performance of alternative urban planning and design proposals (Manum and Nordstrom, 2013; 2015).

In the studies of Oslo, based on the methods developed in the analyses of Trondheim, the mapping included several variables in addition the space syntax street network configuration measures. Among these were perceived danger from heavy traffic, perceived social danger/safety from a lack of people and activities (particularly at night), and attractiveness of routes from the presence of parks, sea/water and other kinds of natural features. Based on the thorough mapping of these aspects of bikeability, the municipality of Oslo has developed ambitious plans for improving the bicycle route network. The analyses of Oslo showed that the choice or betweenness centrality measure is far from sufficient for estimating bicycle flows (Manum and Nordstrom, 2015). Or to put it somewhat different: the measure grasps the potential bicycle flows of the street segments in a bicycle route network, but due factors not captured by the measure, this potential is often hard to achieve. The main reason is perceived safety in terms of fear of being injured at streets cramped by cars, trucks, buses and trams. Instead, many bicyclists use less direct and longer routes that they consider safer.

A conclusion from the Oslo studies is that traffic safety together with bicycling speeds are the main issues regarding bicyclist’ route choice. In addition, and even more important if aiming to increase modal share of bicycling in daily commuting, traffic safety is the main reason for people interested in bicycling not to commute by bicycle. This is in particular the case for women (Nordström, 2013). In conclusion, the studies of Oslo indicate that there is great need for examining bicycling speeds and for including both safety and speed in bikeability modelling. This, together with the research of Dalton (2015) and Broach et al. (2012) arguing for the inclusion of “impedance” along routes in space syntax measures that use spatial and cognitive distance, is the background for the bikeability modelling explored in the case of Gothenburg presented in this paper.

3. METHODS AND MEASURES

3.1 EXAMINING SPATIAL POTENTIAL FOR BICYCLE SPEED ALONG ROUTES

For examining speed potentials, we mapped the speeds of real bicycling along a selection of bicycle routes in Gothenburg. The routes were chosen for being representative of the bicycle route network of Gothenburg and for being relevant references for the planning and design of future bicycle routes. The number of routes examined was 7 and their total distance measured in both directions was 13 km. Figure 1 shows the selected routes.

Then, 15 bicyclists were selected and recruited, representing a variety of daily commuter bicyclists, being between 20 and 66 years old, using different kinds of bicycles and some dressed for exercise while others for relaxed bicycling. In order to check the representativeness of the sample, we carried out a survey on 2000 bicyclists in the same areas of Gothenburg, checking for clothing, bicycle types, gender and likely age. The selected sample showed to be fairly representative, with some bias towards too many participants in the 21 to 35 age range. In order to capture bicycling as daily commuting, the survey was carried out between 07:30 and 09:30 and between 16:00 and 18:00. The speed measurement was done by GPS-tracking with “Cykelstaden”, a software application developed by the traffic office in Gothenburg, together with Clickview, their software for handling the data, mapping the routes and speeds of a total of 875 bicycle trips.

The next part of the study consisted in mapping variables likely to influence bicycle speeds. Since the variables reduce or increase the speed of bicycling, they can be considered speed
MODELLING BIKEABILITY; space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg

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Impedances of the routes. Impedance is a term used in transport analysis meaning resistance to movement, analogous to physics, where impedance measures resistance to electrical current. The street segments, based on a road centre line data set, were processed to create a street network model adapted to capture the different impedances used in this study.

The street segments representing the routes were modelled as a bi-directional system, i.e. with one element in each direction. The street sections between junctions were subdivided into a number of segments that based on their length would give approximately constant bicycling speeds. Breaking and acceleration around junctions was handled by creating a separate segment within 20 meters from each junction. Streets were also subdivided by the kind of bicycle route (see Table 1); in the cases where the kind of route was not constant between junctions, the street was subdivided into segments consisting of only one kind of route. Based on the bicycle speeds' correlates with street curvature described by de Groot (2007), streets with sharper curves than a radius of 10 meters were subdivided into five segments: the curve, adjacent segments of 20 meters (2 pc.) and the remaining ends of the street (2 pc.). Segments where slope varied much were subdivided into lengths with little variation of slope, using the categories 0-2% slope, 2-4% slope and so forth. Finally, the speed impedance variables for the individual segments were assigned, using in the categories listed in table 1.
MODELLING BIKEABILITY; space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg

Unfortunately, the GPS application failed to deliver reliable data concerning waiting times at each intersection, making it impossible to examine the total impedance along routes at the current stage. Therefore, the next step of the research should include a supplemental study on speeds and waiting times at intersections. To estimate speed-models including many dimensions such as impedances along routes and categories of bicycles and bicyclists requires extensive GPS data (El-Geneidy et al., 2007; Romanillos et al. 2016; Arnesen et al., 2017). A way to gather detailed route specific covariates in proceeding research without laborious manual work, is to collect sensor data such as data from an Inertial Measurement Unit (IMU), see Mohanty, Lee et al. (2014) and the references therein, applying for instance accelerometers measuring smoothness of road surface as well as very detailed information of the bicycling speed.

Table 1 - Impedance measures assigned to street segments

<table>
<thead>
<tr>
<th>Impedance variable</th>
<th>Categories / Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kind of route</td>
<td>“pedestrian street, walking-speed street” (walking and bicycling merged)</td>
</tr>
<tr>
<td>Kind of route</td>
<td>“slow bicycling-speed street”</td>
</tr>
<tr>
<td>Kind of route</td>
<td>lane for bicycling at same level and not physically separated from car traffic</td>
</tr>
<tr>
<td>Kind of route</td>
<td>one-way separate lane for bicycling</td>
</tr>
<tr>
<td>Kind of route</td>
<td>two-directional separate lane for bicycling</td>
</tr>
<tr>
<td>Kind of route</td>
<td>bicycling and walking lane (merged, but separate from car traffic)</td>
</tr>
<tr>
<td>Width of bicycle lane</td>
<td>Metres</td>
</tr>
<tr>
<td>Kind of bicycle lane surface material</td>
<td>Asphalt</td>
</tr>
<tr>
<td>Kind of bicycle lane surface material</td>
<td>Concrete</td>
</tr>
<tr>
<td>Kind of bicycle lane surface material</td>
<td>Natural stones</td>
</tr>
<tr>
<td>Kind of bicycle lane surface material</td>
<td>Gravel</td>
</tr>
<tr>
<td>Kind of separation from pedestrians</td>
<td>Furniture, vegetation etc</td>
</tr>
<tr>
<td>Kind of separation from pedestrians</td>
<td>Height difference (different level)</td>
</tr>
<tr>
<td>Kind of separation from pedestrians</td>
<td>Different surfaces</td>
</tr>
<tr>
<td>Slope</td>
<td>Percentage (%)</td>
</tr>
<tr>
<td>Horizontal curvature (radius)</td>
<td>Degrees</td>
</tr>
<tr>
<td>Length of segment</td>
<td>Metres</td>
</tr>
<tr>
<td>Distance between junctions</td>
<td>Metres</td>
</tr>
<tr>
<td>Segment connected to junction</td>
<td>Yes \ No</td>
</tr>
<tr>
<td>Entrances along segment, within 15m from segment</td>
<td>Count / 100 metres (All kinds of entrances to buildings, within straight line distance)</td>
</tr>
<tr>
<td>Entrances along segment, within 30m from segment</td>
<td>Count / 100 metres (as previous)</td>
</tr>
<tr>
<td>Car parking</td>
<td>Yes \ No</td>
</tr>
<tr>
<td>Bus stop</td>
<td>Yes \ No</td>
</tr>
</tbody>
</table>
The final step in modelling consisted in assigning the value of each impedance variable to every separate street segment. Some variables, such as slope, curvature and length of segments, were generated automatically from GIS. Others, such as kind of route, surface, width and separation type, required a combination of examining ortho-photos and site surveys. All the variables of speed impedance modelled in GIS are the data to be compared with the empirical data of bicycling speeds extracted from the GPS-tracking.

All the impedances considered were added to the statistical model for calculating their impact on bicycle speed. To find the most important independent variables and test their significance, a multiple regression analysis (OLS) was performed. The level of significance used was 0.05. Finally, the R² value was calculated to see how much of the measured variation could be explained by the variables in this study.

3.2 EXAMINING STRUCTURAL SPATIAL POTENTIAL FOR BICYCLE FLOW ALONG ROUTE

The second part of the method, modelling flow potential, is based on space syntax theories and measures. Flow potential is here about predicting the amount of bicyclists along street segments. It is not based on the impedance of the segments like the speed model, but rather on their location in the street network relative to all other segments. Segments with higher network centrality according to various measures are expected to have more bicyclists due to their higher potential, which can be interpreted as being more important for the network as a whole.

The empirical data used were gate counts of bicycle flows at 174 points, conducted by the municipality of Gothenburg in 2014 (Björklind, 2015). The counting was done during rush hours 07:00-09:00 and 15:30 – 17:30 and during lunchtime 11:30-13:30. In this project, the unit applied is the daily average of these counts, measured as number of bicyclist per hour.

The next step consisted in identifying the urban form variables to examine. The street-network model examined was a bicycle route segment map based on an axial line map provided by the consultancy firm Spacescape. The selection of variables was based on experience from previous research. Altogether, 21 street-network analyses were conducted, examining 6 spatial measures and 3 different distance thresholds for each measure (Table 2).

<table>
<thead>
<tr>
<th>Measure</th>
<th>Analysis parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial integration</td>
<td>Topological distance, topological radius along the network (7, 12, N)</td>
</tr>
<tr>
<td>Segment angular integration</td>
<td>Angular distance (least angular change), metric radius along the network (3000, 5000, 10000 m)</td>
</tr>
<tr>
<td>Segment angular choice</td>
<td>Angular distance, metric radius along the network (3000, 5000, 10000 m)</td>
</tr>
<tr>
<td>Accessible population</td>
<td>Total number of residents and workplaces, metric radius along the network (3000, 5000, 10000 m)</td>
</tr>
<tr>
<td>Attraction betweenness</td>
<td>Angular distance, metric radius along the network (3000, 5000, 10000 m), with accessible population as attraction weight.</td>
</tr>
<tr>
<td>OD-betweenness</td>
<td>From residents origins to workplaces and enrolled students and vice-versa, angular distance, metric radius (3000, 5000, 10000 m)</td>
</tr>
</tbody>
</table>

Table 2 - Spatial network measures calculated
Besides the commonly used measure of axial integration, segment angular integration and choice, calculated in Depthmap 10, we also examined two variations of the space syntax choice measure recently implemented in the Place syntax tool (Ståhle et al, 2005), called Attraction betweenness and Origin-destination betweenness or OD-betweenness. Attraction betweenness, as used by Berghauser-Pont and Marcus (2015), is similar to segment angular betweenness in terms of scoring each segment along the shortest angular route, but differs by multiplying the score with an “attraction”. In this study, examining potential flows of bicycling, the “attractions” are the population accessible within a metric threshold distance. In OD-betweenness, each segment is scored for being on the shortest routes between a set of origins and a set of destinations, instead of routes between all nodes of the network. The score, assigned to the segments, is a combination of the weight of the origin (number of residents) multiplied by the normalised weight of the destination (i.e. dividing the destination weight by the sum of all destination weights). The network analysis in this study operates on three data sets: a set of address points of residents (the origins), a network graph of segment lines representing all possible routes and a set of address points of workers and enrolled students (the destinations). Every address point is linked to the nearest axial segment in the network. First the calculation uses metric distance for the radius threshold, then, it uses angular distance (least angular change) for the shortest route calculation, as specified in the parameters of the spatial measures in Table 2.

Whereas the first regression model deals with speed potential, the second regression model deals with flow potential, mainly testing structural properties of the street segments related to all the other segments in the network. Similar to the first, multiple regression analysis (OLS) is used to test various predictor variables and find their significance and importance in explaining the variation in the observed bicycling flows.

4. RESULTS

4.1 THE SURVEY DATA

Table 3 shows a summary of the GPS speed data, whereas Table 4 shows the results for each of the 7 routes. Figure 1 maps the speeds along the routes by colour range, showing speeds in both directions. The results include all segments except the 20 m segments closest to junctions. These segments are excluded due to an automatic functionality of the GPS-unit causing unreliable speed data close to or in combination with full stops. As expected, due to the slope, bicycling speeds at the hill north of the river are among the fastest as well as the slowest, depending on direction of travel. Not surprisingly, we also see that speeds are very low on routes including numerous traffic-light junctions, such as parts of Östra and Västra Hamngatan, see Figure 1. The average speeds differ significantly across different routes, being 40% slower at Västra Hamngaten than at Göta Älvbron, 13 and 21 km/h, respectively. This illustrates the need for developing models handling bicycling speeds as a measure dependent on route properties at a detailed scale. The range of speeds is similar to former studies dealing with bicycle speeds. Most studies show free flow speed varying between 14 km/h and 20 km/h in urban contexts (El Geneidy et al., 2007; Cheng Xu et al., 2015).
MODELLING BIKEABILITY; space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg

<table>
<thead>
<tr>
<th></th>
<th>Median speed</th>
<th>85 percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gōta älvbron</td>
<td>21</td>
<td>30</td>
</tr>
<tr>
<td>Lindholmsallén</td>
<td>21</td>
<td>27</td>
</tr>
<tr>
<td>Vasagatan</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>Nya allén</td>
<td>16</td>
<td>26</td>
</tr>
<tr>
<td>Kyrkogatan</td>
<td>16</td>
<td>20</td>
</tr>
<tr>
<td>Östra Hamngatan</td>
<td>14</td>
<td>24</td>
</tr>
<tr>
<td>Västra Hamngatan</td>
<td>13</td>
<td>23</td>
</tr>
</tbody>
</table>

Table 3 - Summary of speed tracking on the bicycle routes, averaged for both directions

4.2 THE BICYCLING SPEED MODEL

The first analysis, examining impedances expected to affect the median speed on the street segments, shows that nine predictors are significant and contribute to the explanation (see table 5). Their explanatory usefulness varies, but not to a large extent. The variance inflation factors (VIF) show that the variables do not covariate to any considerable amount. The F-value for the whole model is significant, which shows that at least some of the prediction variables contribute to the explanatory power of the model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstand. Coef.</th>
<th>Stand. Coef.</th>
<th>t</th>
<th>Sig.</th>
<th>Correlations</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>14,491</td>
<td>16,007</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connected signal intersection</td>
<td>-5,430</td>
<td>-4,86</td>
<td>-1972</td>
<td>0.00</td>
<td>-452</td>
<td>-470</td>
</tr>
<tr>
<td>Number of entrances 30 meter</td>
<td>-0.025</td>
<td>-0.147</td>
<td>-0.034</td>
<td>0.00</td>
<td>-317</td>
<td>-173</td>
</tr>
<tr>
<td>Slope downhill</td>
<td>0.999</td>
<td>0.256</td>
<td>6.297</td>
<td>0.00</td>
<td>-0.353</td>
<td>-0.245</td>
</tr>
<tr>
<td>Pedestrian street</td>
<td>-2.399</td>
<td>-0.148</td>
<td>-0.03</td>
<td>0.00</td>
<td>-0.272</td>
<td>-0.173</td>
</tr>
<tr>
<td>Double sided bicycle track</td>
<td>1.350</td>
<td>0.171</td>
<td>3.813</td>
<td>0.00</td>
<td>0.249</td>
<td>0.217</td>
</tr>
<tr>
<td>Horizontal curvature</td>
<td>0.029</td>
<td>0.234</td>
<td>3.331</td>
<td>0.00</td>
<td>0.062</td>
<td>0.191</td>
</tr>
<tr>
<td>Length of segment</td>
<td>0.012</td>
<td>0.003</td>
<td>0.01</td>
<td>0.00</td>
<td>0.039</td>
<td>0.243</td>
</tr>
<tr>
<td>Slope uphill*segment length</td>
<td>-0.005</td>
<td>-0.171</td>
<td>-3.684</td>
<td>0.00</td>
<td>-0.040</td>
<td>-0.210</td>
</tr>
<tr>
<td>Natural stone</td>
<td>-1.193</td>
<td>-0.120</td>
<td>-2.537</td>
<td>0.012</td>
<td>-0.236</td>
<td>-0.247</td>
</tr>
</tbody>
</table>

Table 4 - The results of the multiple regression analysis (OLS) for median speed potential.
### Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>R Square Change</th>
<th>Change Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 5</td>
<td>.740</td>
<td>.548</td>
<td>.534</td>
<td>2.68861</td>
<td>.010</td>
<td>6.434 1 293 .012</td>
</tr>
</tbody>
</table>

Table 5. Summary of the multiple regression analysis for median speed potential.

**i. Predictors:** (Constant), Connected signal intersection, Number of entrances_30 meter, Slope downhill, Pedestrian street, Double sided bicycle track, Horizontal curvature, Length of segment, Slope uphill*segment length, Natural stone

**j. Dependent Variable:** Median speed

Figure 2 - Residual plot for speed model.
Figure 2 shows the residual plot for the speed model. Even though the plot seems fairly random, it is not completely ruled out that the residual plot can hide some variable not taken into account, for example prevailing wind directions and delays caused by congestion. The R² of the model is 0.54, which mean that the selected variables explain 54% of the speed variations (table 6). Having the complexity of bicycling flows in mind, this is an acceptable result, particularly when also having in mind the potential improvements that can be made to the model in the future. One example is to the effect of slope, which currently is modelled in intervals, but with continuous modelling the effect might improve the model. Figure 3 shows the median speed from the GPS data (left) compared to the median speeds estimated by the regression model.

Figure 3 - Speed from GPS-tracking (left) and estimated by the model (right)

4.3 THE BICYCLING ROUTE MODEL

The second model, dealing with network measures expected to predict the potential for bicycle flows, also explains the measured variations to a fair extent. All variables are significant and contribute to the explanatory capability of the model. Their explanatory power varies, according to the coefficients seen in table 7, but not to a large extent, and OD-betweenness is the most significant. This can be explained by the fact that OD-betweenness can be considered to measure the potential amount of bicycle trips to work, which according to travel survey data is the most frequent bicycle trip in Sweden (Saxton, 2015).

At first glance surprisingly, accessible population within 1 km correlates negatively with bicycle flows. Looking closer, the variable has a positive correlation up to a certain accessible population, and is negative in the densest parts of Gothenburg. This explains that accessible population is a proxy for low speed potential, which implies that bicyclists choose alternative routes in less dense parts of the city. This corresponds to the results related to route choices in Oslo (Manum and Nordstrom, 2015).
MODELLING BIKEABILITY; space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg

Table 6 - Multiple regression analyse (OLS). Bicycle flow potential

A closer look at variance inflation (VIF) shows larger values than the first analysis, up to 3.4 seen in table 7, although they are judged to be acceptable in this analysis. The F-value for the whole model is large and significant, which indicates that at least some of the predictors contribute to the explanatory power of the model. The residual plot from the analysis is random.

Table 7 - Model summary for bicycle flow potential
Finally, the $R^2$ of the model is 0.45, which mean that 45% of the variations in the measured flow can be explained by the selected predictors. This is lower than the speed model result (0.45 compared to 0.54), and can be explained by the large number of relevant issues not included in the model. Some variables that according to research are essential for route choice not yet included in the model are the differences in speed and the feeling of safety and comfort (Spacescape, 2015). For example, some fast commuter routes along the water have low betweenness values while they have many bicyclists. On the other hand, many of the busiest streets have high betweenness values but few bicyclists. This confirms patterns found in previous research (Manum and Nordstrom, 2015). The discrepancy of the betweenness measures and flows of bicycling at particular kinds of routes can be explained by bicycling speeds and traffic safety. The separate commuter routes allow for convenient and fast bicycling, implying that bicyclist choose these routes for being the quickest and easiest despite unfavourable metric distance. Regarding the busy central streets, these are often crammed with traffic, in some cases large amounts of cars as well as trams and buses, and in other cases pedestrians. The first cases are dangerous for the bicyclist; the second cases force the bicyclist to slow down and give priority to pedestrians. In both cases, it is often more convenient, safer or quicker for the bicyclist to choose alternative routes, even though they might be longer in metric distance or cognitively less direct. To conclude the discussion of the results, a possible issue with the bicycle network representation should be mentioned. An important measure in the analysis is angular change at junctions. This research project used an axial map produced for other purposes, without comparing the angles at junctions in this axial map with the geometries of real bicycling routes through junctions. Such comparisons should be part of future research, likely resulting in more detailed modelling of lines at junctions and an improved model.

5. CONCLUSIONS

This project illustrates the variety of bicycling speeds along urban routes and sheds light on the relative influence of some particular bicycle route variables significant for bicycle speeds. In addition to the obvious result that downhill slopes correlate with higher speeds whereas signal crossings correlate with lower speed at adjacent segments, the most significant of the variables examined were: many entrances along the segment (-), mixed use with walking (-), two-way bicycle lanes (+), radius of curvature (+) and length of segment (-). As mentioned earlier in the paper, there is a need to handle bicycle speed and route properties at a detailed scale. In the work of Arnesen et al. (2017), a Markov model for predicting bicycle speed along a route with high resolution considering vertical and horizontal curvatures is being developed for this purpose. In this Markov model, the speed in the current road segment is dependent of the speed in previous and future segments, providing more realistic speed profiles. A suggestion for further work is therefore to include the larger variety of covariates presented in this paper into this more advanced methodology of speed modelling.

Regarding bicycle flows, the project has examined a selection of space syntax based spatial measures, measures that can be mapped directly from GIS. The latter is important to apply the analysis tools on large urban systems. The most significant variables regarding bicycle flows are OD-betweenness least angular change within 5km (+), segment angular integration within 10 km (+), accessible population within 1 km (-) and network betweenness (as shortest distance) within 3 km (+). Even though bicycle flows are influenced by many personal, social and economic issues to ever be fully grasped by space syntax models and GIS-analyses, this project shows that several of the measures examined, particularly the OD-betweenness, convincingly capture the main patterns of bicycle flows. Due to the importance of bicycle speeds and traffic safety on route choice and these issues not being included in the current model, adding variables influencing those factors should significantly improve the correlation with flows of real bicycling.

Based on this conclusion, the main issues for future research are to examine how speed differences, perceived safety and convenience can be analysed in GIS based tools that include space syntax measures. One way of achieving this is to convert traffic safety and convenience into added travel time. This method has been discussed in transport research (Ellis, 2015) and
is currently work in progress within the research project Stratmod (Norheim and Tørset, 2015) where impedance values from the aforementioned report is used to calculate generalised time for each road segment. Another option, suggested by Dalton (2015) is to add impedances into a spatial configuration model by converting impedances, for instance the effect of traffic signals, into weights added to topological distance. Based on the results of the current project, our approach to further research will be to elaborate on the OD-betweenness analyses by including speeds and ideally traffic safety into the betweenness measure. The first step, in addition to improving the speed model to include the range of speeds caused by different kinds of bicycles and bicyclists and by impedances along routes, will be to convert speeds on the segments into time and then apply trip time rather than metric distance as the radius/threshold unit in the spatial analyses. By measuring time along segments (intersection impedances included), it should be possible to develop a new and improved generation of space syntax based accessibility analyses - analyses where the bicycling potential of a bicycle route network is based on spatial configurations but also on “time and convenience” of real bicycling at the routes. A working title for the new measure is “least impedance origin destination betweenness”.

ACKNOWLEDGEMENTS

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MODELLING BIKEABILITY; space syntax based measures applied in examining speeds and flows of bicycling in Gothenburg


#90
GATEWAY-PATHWAY HERITAGE AND URBAN GROWTH
Zagreb case study

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ABSTRACT
This paper is a part of on-going research into the typological definition of ‘urban gateway-pathways’. This term refers to routes used to connect peripheral settlements to the urban core of contemporary cities. The typology was developed with reference to a sample of 18 Central European cities that were formerly provincial capital cities of the Austro-Hungarian monarchy. This paper provides the first authoritative syntactical description of the city of Zagreb and reports on initial syntactical analysis of its historic pathway typology using the transect method established by Hillier (1999). The results from the transect analysis are then used to provide more refined typological descriptions of the gateway-pathways and their historical transformations, and to frame a future phase of research using segment analysis.

KEYWORDS
Gateway-pathways, space syntax transect analysis, Zagreb, Croatia

1. INTRODUCTION
This paper reports on-going research into transformations of historical ‘gateway-pathways’ (Maric and Jaksic, 2011; Maric et al. 2014). ‘Gateway-pathways and roadways’ refer to those routes which lead, or used to lead, into the urban historical core of a settlement. Need for terminological distinction from other historical paths, roads and networks, came out from the importance of these routes in urban formation processes during the growth of the cities. The effort is to suggest a process-driven appreciation of heritage, rather than a static, object-driven approach. To explore these linear processes along specific routes and emphasise the importance of these streets we aim to introduce the name ‘gateway-pathways’ and typological study.
Research is applied on Central European case studies\(^1\), where gateway-pathways are identifiable from historical maps made under the Habsburg rule (Biszak et al., 2014)\(^2\). The territory of the Austro-Hungarian monarch was mapped by military surveys using the same technique three times: 1763-1787, 1806-1869 and 1869-1887 (fig. 1). The identification of the historical urban core and historical gateway-pathways in the surveyed cities depends on the date of the first survey (fig. 2). In all cases the survey took place before the rapid urban twentieth-century growth of these cities. The sample of 18 cities selected for exploring historic gateway-pathway as a dimension of urban heritage, were formerly the main provincial cities of the Austro-Hungarian monarchy\(^3\).

An initial typological classification of historical gateway-pathways and their transformations was derived from a comparative evaluation of the routes connecting the urban periphery to the historic core based on two criteria: (a) the relationship of the pathway to the urban core and periphery; and (b) the transformation of the pathway or in other words, the contemporary state of the pathway. Criterion (a) was assessed based on route formation, topography and urban growth processes; and criterion (b) was based on the contemporary status of the pathway, and the changes on the original/historical pathway form and its role for the city.

Based on a comparative examination of the historical military survey maps for 18 Central European cities, the categories of typological classification of gateway-pathways were developed. The types are: a) ‘regional direct gateway-pathways’ connecting other towns and settlements with the defined walled city; b) ‘local direct gateway-pathways’ connecting the walled core with northern slopes towards the mountain, and c) ‘transit gateway-pathways’ leading to the historical core of the built environment beyond the historically defined and walled town. From this classification, the city of Zagreb was selected for further investigation using space syntax in order to evaluate the typological categories of historical gateway-pathways by applying a formal analytical method of spatial-morphological description\(^4\). In this paper, we will explore the spatial morphological description of the last category – ‘transit gateway-pathways’ as the dominant gateway typology for Zagreb.

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1 On-going research refers to doctoral research undertaken at Vienna Technical University (TUW) by PhD student Tamara Marić that is also part of Heritage Urbanism project at The Faculty of Architecture, The University of Zagreb.

2 Database from Arcanum project (mapire.eu)

3 Vienna, Budapest, Prague, Ljubljana and Zagreb as also state capitals in the 21st century with all three military survey maps are explored in more detailes while other cities (Sarajevo, Lavov, Brno, Graz, Chernovitz, Trieste, Linz, Salzburg, Innsbruck, Klagenfurt, Zadar, Opava, Bregenz) are used only for initial typology identification.

4 This work was done as guest research at UCL Bartlett in 2016 and is partially supported by the Croatian Science Foundation under the project Heritage Urbanism – Spatial and Urban Models for Revival and Enhancement of Cultural Heritage (HRZZ 2032 project; head of the project Prof.dr.sc. Mladen Obad Scitaroci)
Zagreb occupies a specific topological urban situation with bi-nucleated urban core located on the hills between the mountain of Medvednica and the river Sava (fig.1-3). Two historical settlements were merged into one city together with the main square outside the walled settlements and surrounding houses gathered along the main gateway-pathway routes in 1850. Rapid growth in the second half of the 20th century extended the main urban area to include surrounding village settlements. Zagreb’s municipal authority, with a series of architectural and master planning competitions, continuously developed new routes for entering the city in areas without historic pathway network. Consequently, the historical gateway-pathways in Zagreb have kept their distinctiveness to different extents, depending on how they were located in relation to the subsequent development of railway and motorway infrastructure. The main research question addressed in this paper concerns identifying whether syntactical measurements can be used to describe these typological differences, thereby enabling researchers to better understand the definition of ‘gateway-pathways’.

The body of research in space syntax theory on central European cities is limited. Dino et al (2015; 2016; 2017) look diachronically at morphogenetic transformation of Tirana (Albania) by contrasting the built form and the road network during two distinctively different political ruling ideologies, while Shpuza (2009; 2014) gives detail comparison of Adriatic and Ionian cities among which are two cities used for typological identification of gateway-pathways in this research. In addition to its primary focus on gateway-pathway, therefore, this paper also provides an introduction to inform spatial-morphological comparison of Zagreb with more commonly investigated UK and Mediterranean examples. It gives insight into preliminary research questions, methodologies and results pertaining to the Zagreb case study, which can be used for developing comparison with other Central European cities. In this context, the paper’s specific aim is twofold: (1) to use space syntax measurements, descriptions, and tools to evaluate the typological and terminological notion of gateway-pathways, and (2) to develop a mapping method involving the historical ‘decoding’ of a syntactic model of contemporary Zagreb using the historical cartographic surveys, in order to identify new possibilities for using space syntax theory and methods in historical research.

2. THEORETICAL AND METHODOLOGICAL BACKGROUND

The development of systematic spatial-morphological descriptions in historical studies is growing as a popular inquiry in space syntax research. Historical urban-scale research using space syntax methods takes a variety of forms (Griffiths, 2012), and includes a series of studies of urban structures that can be considered as gateway-pathways. Such examples are the syntactic descriptions found in the study of transformation processes of the historic cores of Iranian and English cities by Karimi (1998), of the English industrial city of Sheffield by Griffiths (2009), of the London suburban development by Griffiths et al. (2010), as well as in the study of spatial sustainability as an organic process of the street network in cities by Hillier (2012). While spatial-morphological descriptions of city structures in general, and amongst them of city elements that were historically gateway-pathways in particular, have advanced in the context of space syntax historical studies, still gateway pathways – as historically structural routes to and from the urban core – is a theme that has not been either systematically – typologically addressed – or particularly considered in heritage context. This paper aims to explore the theoretical and methodological prospects of gateway-pathway research in historical and heritage studies using a syntactical understanding of cities.

The methodology developed for this paper poses two main questions. The first has a wider context in space syntax approach: namely, to what extent is it possible to identify historical transformation processes in streetscape through a process of ‘decoding’ axial and segment graphs instead of using the cartographic redrawing method? The second question is case-related: namely ‘of what value are the current typologies of gateway-pathways being used in research on Central European cities, and which syntactical measures will be of the most value in developing the typologies?'
Research into gateway-pathways involves examining changes in the relation between the urban historical centre and peripheral areas of the city by tracing transformations in the urban tissue of their connecting paths, roads, and centralities. Along these pathways, we can track transformation processes from trail to path, to road and urban street, and finally as part of the ‘urban landscape’ of streets connecting different public places from the centre to periphery. They have (or ought to have) specific recognition in heritage context because they are not only continuously present (in some form) from the early history of the city but they are also, necessarily, connections to the protected historical centre. For Hillier (1996, 339-345; 1999) what we identify as gateway-pathways comprise a critical generic feature of emergent urban growth, meaning that as cities grow and increase in density at the centre, they preserve a globalising linear structure that carries integration from the urban core to the (segregated) urban exterior. Theoretically, it is this powerful identification and mathematical description of the formative processes of the core structure in the urban landscape by Hillier (1999) that is of fundamental significance for testing typological classification of gateway-pathways.

In explaining ‘centrality as a process’ Hillier suggests a globally structuring pattern of grid deformation along the main routes and off the main routes, which occurs as local grid conditions adapt over time and the grid densifies by forming smaller scale urban blocks and more trip-efficient routes. Gateway-pathway relates to ‘centrality as a process’ because it investigates pathway development and transformation of routes along continuous or near-continuous transects with the focus on identifying the particular trajectory of pathway development and historical ‘break incidents’. Relying on the fact that integration analyses show live centres (ibid.) within transect method, we will attempt in this paper to systematically address the historical emergence of gateway-pathways in spatial-morphological terms by comparison method with other streets in Zagreb network and by adapting Hillier’s transect method.

Transect analysis (ibid.) was chosen as the most appropriate syntactic method for comparing four case study pathways in the preliminary stage of analysis for two reasons. First, patterns derived from 2-step transects can overlap with the network of 10% most integrated axial lines which should show differences due to different typological categories in the way gateway-pathways initially led to the historical settlements. Second, it allows historical understanding without using cartographic redrawing methods due to careful choosing of the transect axial lines enabled by georeferencing historical maps either scanned (Škalamera, 1994) or used from mapaire.eu (Biszak et al., 2012) in ArcGIS, where the axial model of Zagreb was also drawn. Cartographic redrawing methods are now well established as a form of syntactic-morphological analysis (Pinho and Oliveira, 2009; Dhanani 2016). This approach, which involves working backwards from contemporary maps to create syntactical models of past urban environments is time consuming, which explains why comparative case studies are rare.

Following a baseline spatial morphological description of the Zagreb model in chapter 3, axial and segment analyses are used to compare the spatial configuration of gateway-pathways in the overall spatial configuration of Zagreb street system in chapter 4 and table 3. The degree of change in the network is measured by the breaks in continuity and, on the basis of this, the typology is tested in chapter 5 with comparative descriptive approach on a sample of four gateway-pathways transects. The basis for transects as selected lines or zero-step-depth lines were historical lines detected as preserved in contemporary axial map from original gateway-pathway route.

This study is focused on four Zagreb transit gateway-pathways as dominant typology with different roles in contemporary urban network. We will call these pathways: (1) Ilica; (2) Vlaska; (3) Savska, and (4) Petrinjska, while noting that they include other streets as well along their historical and contemporary lines. In Zagreb, there are three types of transit gateway-pathways according to placement and transformation degree. The first are Ilica and Vlaska pathways which kept the east-west continuity by keeping the irregular linear character in the layout plan closed to historical center and which together with the main public square create

\[\text{Historical lines are derived from the continuity path on the historical military survey maps, while contemporary lines is continuity direction after route transformations during the urban growth. These differences are measured by the number of breaks between historical and contemporary lines in the table 4.}\]
one axis in the Zagreb urban plan. The second, Savska street, is an avenue type of street which was in part redirected with the new bridge connection in 1981 from its original route layout onto contemporary route as new traffic entrance to the city, while original parts from 18th century have more of a local route character. The last type is Petrinjska Street as the pathway with discontinuities (or ‘disappeared gateway’), which is a comparative rare classification in all the analysed cities.

3. SYNTACTIC PROFILE OF ZAGREB

Zagreb is bi-nucleus city with its medieval centres of Gradec and Kaptol located on two hills (fig. 2 and 3). Both centres were walled and at a distance of 2.8 km from the River Sava\(^6\), on the slopes of Medvednica mountain. The Roman settlement and port on the Sava River was Andautonia south-east of Zagreb’s historical core and not a part of contemporary fabric of the city. The exact routes of the Roman roads passing through the area of the city have not yet been precisely identified. There are indications of a southern connection from east to Siscia, and possibly east-west connection with Andautonia which was a regional gateway-pathway as Ilica and Vlaska later in history\(^7\). The difficulties of mapping geolocations of ancient historical pathways are the reason why typological identification was done using high quality military surveys from 18th to the beginning of 20th century. For Zagreb, the areas of original route of gateway-pathways and the historical urban core as the built urban fabric are visible from the first military survey mapped in 1783-84 (fig.2). Typological identification described in introduction and methodology was done before making axial map and syntactical model of Zagreb. Therefore, we decided to create contemporary model for the purpose of finding out if and how original routes can be detected after transformation processes.

This city of Zagreb is one of the 21 counties in Croatia. That defines the city by its administrative area boundary – an area which is not equivalent to the built-up area of the city. Therefore, there were two main criteria in defining the size of the syntactical model: 1) natural topographical boundaries – the mountain to the north and river to the west and south-east\(^8\), and 2) ‘hard’

\(^6\) This is a distance from contemporary cannal form of the Sava river.
\(^7\) http://pelagios.org/maps/greco-roman/
\(^8\) Medvednica mountain is under natural park state protection with strict building restrictions which makes clear the boundary of urban area.
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Figure 3 - The city of Zagreb – 21st century aerial view with: 1=Ilica gateway contemporary, 1’=Ilica historical gateway-pathway route in contemporary urban form, 2=Vlaska gateway contemporary, 3=Savska gateway contemporary, 3’=Savska historical gateway-pathway route in contemporary urban form, 4=Petrinja historical pathway traces in contemporary urban form; a=Zagreb central planned axis, b=Vukovarska street (modernistic street), c=Zagrebacka avenue (contemporary western gateway route to the city); A= Maksimir park, B= Bundek park and the hippodrome, C= Jarun recreational park and dashed-white area of Gradec and Kaptol (Up-town, north) and 19th century block planned structure (Down-town, south)

infrastructure boundaries — including the detour motorway to the south and east\(^9\). The map is approximately 20x10 km in layout size about an equivalent area to the Zagreb Master plan.

The axial model was drawn using ArcMap software and GIS data layers of buildings and transportation network from the city municipality of Zagreb\(^10\). The map was done from scratch having orthophoto map\(^11\) from 2012 as the basis for drawing and overlapped with the database of vectorised and georeferenced buildings layer distributed with colours by purpose for exact positioning the length of the axial lines and areas of roads from the transportation network which helped in peripheral areas (industrial and retail) as the places where people move. The model includes all main urban public spaces as streets, squares and parks together with pedestrian zone. These pedestrian areas were mapped according to pedestrian traffic layer combined with data from terrain experience and OpenStreetMap ArcMap base layer. Three large-scale urban parks are excluded from the map because they are closed pedestrian subsystems at a different scale from the open street network of the main part of the city. These are: Maksimir park with the zoo area, Bundek park near the Sava river with the lake and the hippodrome area and Jarun park area which is the main recreational area of the city. The Banks of the Sava River with the embankment system are mapped as a part of pathway system. The 19th century blocks are mapped together with the passages and block entrances where the public buildings are inside the block areas. The northern part of the city with Medvednica slopes includes pedestrian stairs which are characteristic connection feature for that area. The steps are drawn with broken axial lines — increasing depth to indicate the difficulty in pedestrian movement.

Comparison of scales in the main axial measurements of Zagreb with the data of Greater London was done in order to understand the scale of the city better in syntactical measurements (Table 1). Zagreb’s district area is almost two and a half times smaller in scale than London (641km\(^2\) Zagreb and 1572km\(^2\) London area). In terms of population London is more than ten times larger (790,017 – Zagreb; 8,673,713 – London), and when it comes to density, it is four and a half

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\(^9\) which means that until that scale transformations of historical gateway-pathways are observed.

\(^10\) City Office for the Strategic Planning and Development of the City / Gradski ured za strategijsko planiranje i razvoj Grada, Sektor za strategijske informacije i istraživanja

\(^11\) https://geoportal.zagreb.hr/PopisServisa.htm
times denser (1232 per km2 – Zagreb; 5,518 per km2 – London). The syntactic analysis shows that Zagreb has seven and a half times fewer axial lines in system size. Both models are drawn within the motorway system as a ‘hard’ boundary, but while administrative boarders of London are within M25 area, Zagreb’s administrative border is wider than the model size and motorway system half-ring, with a lot of natural and empty areas in between.

From the table 1 we can see that London overall has higher connectivity values in both the entire systems and 10% integration core. Line length max and mean is larger for the entire system in London while Zagreb has a bit larger lines length in 10% integration core. Situation is more complex for integration, at Integration HH Zagreb has higher values, while London has higher values for Integration HH R2.

Zagreb’s axial integration (fig. 3) shows that its historical nuclei of Gradec and Kaptol (up-town) are not part of top integration values or 10% integration core. Instead 10% integration core of Zagreb is covers entire the 19th century block structure (Down-town), central axis connecting New Zagreb area across and south from Sava River with the areas along the Savska diagonal and its complementary street on the east (Radnicka road and Drziceva avenue). These diagonals and east-west connection streets in the 10% integration core are contemporary entrances or gateways from periphery to city central areas.

<table>
<thead>
<tr>
<th></th>
<th>Zagreb</th>
<th>London</th>
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<tbody>
<tr>
<td></td>
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<td>10% Integration Core (Number Of Lines = 1323)</td>
</tr>
<tr>
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<tr>
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<td>172</td>
</tr>
</tbody>
</table>

Table 1 - Comparison of axial analysis values for connectivity, integration and line length between Zagreb and London in the overall system and 10% integration core.
Table 1 gives inside to axial analysis measurements for the entire Zagreb system, and this was used for comparison with gateway-pathways in Table 3. Segment analyses were used according to Hillier’s star model (2012). In comparison with other cities Zagreb shows balanced foreground-background numbers in star model. Its star model diagram is similar to Barcelona and numbers are in between Barcelona and London diagram model (fig. 5). The biggest differences are in the mean choice value where London has the lowest value. This could be interpreted in combination to Integration HH values whose mean value is more higher for the 10% integration core than for London that Zagreb core stands out more in the overall system, the same relation of choice shows star diagram in Barcelona whose core morphological is very contrasted to the block system network as the foreground pattern.

When star model was done for four case study gateway-pathways the results were too similar to the star diagram for Zagreb overall system Rn, therefore the decision was to include in this study transect overlap with 10% integration core derived from axial measurements.

4. SYNTACTICAL PROFILE OF GATEWAY-PATHWAYS

In order to understand urban growth processes in the city of Zagreb we compared historical gateway-pathways (1 Ilica, 2 Vlaska, 3 Savska and 4 Petrinjska) with mentioned new entrances of Vukovarska, Central axis and Slavonska-Zagreb avenue since they are also a part of 10% integration core (fig.2). Research questions for the comparison methodology were: (1) ‘can historical pathways be identified as such and how?’, and (2) ‘can typological differences be detected in the contemporary axial measurements through this comparison’?

Historical pathways were identified through selection process in ArcGIS by comparing syntactical model to the georeferenced historical maps. For the gateway-pathways case studies the historical and contemporary axial lines measurements were taken into the table 2 for detail comparison.

The elements of the comparisons in table 2 are basic axial measurements: max and mean in integration HH, integration HH R2, connectivity and line length. They are columns together with the number of lines and their sum value. If we look at rows of the table 2 the situation is more complex to show the identified historical and contemporary differences.

In the first row, there are the measurements for the entire system of Zagreb and all other rows are values for parts of the city. These parts are selected as axial lines representing the streets which are being compared: four historical gateway-pathways and three new planned avenues from 20th century. Solid lines between the rows in table 2 separate information for each of the city part or entrances whether it is historical gateway-pathway or not, while selections related
to the same route are separated with dashed lines. Also, there are selections where the historical and contemporary layouts of the route do not match due to some breaks in the original line length and its transformation processes. Therefore, historical gateway-pathways are selected in three ways, depending on which one was possible to detect: 1 – as lines of contemporary routes in the city as they are in the 21st century (marked as cont.* in the table); 2 – as streets in the length as they are today (marked in the table as st.); and 3 – as historical pathways where selection was mostly discontinuous because the criteria was to select axial lines which remained from the initial historical gateway-pathway as they were on first or second military survey maps depending on which had better correlation to the contemporary map after georeferencing.

The table 2 enables multiple comparisons. Firstly, we can compare linear parts of the cities (streets, pathways) with the entire urban system of Zagreb. Secondly, there is a comparison of those routes which have historical background from before 20th c. and planned axis introduced in the 20th c. (in the table: Vukovarska st., Central axis** and Zagrebacka av.). Thirdly, comparison is possible for the historical gateway-pathways between the form of its historical and contemporary route which appeared during urban growth and spreading of the urban fabric.

In the table the highest values are marked in red and the lowest in blue. Both historical gateway-pathways and analysed 20th century arterial streets in the table 3 show similar characteristics when compared to the whole urban network: high maximum values of Integration HH – very

<table>
<thead>
<tr>
<th></th>
<th>Integration Hh</th>
<th>Integration Hh R2</th>
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<th>Line Lengths And Number</th>
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<td>Petrinjska st.</td>
<td>0.732009</td>
<td>0.712289</td>
<td>4.2445</td>
<td>3.593451</td>
</tr>
<tr>
<td>Petrinjska hist.</td>
<td>0.732490</td>
<td>0.68711</td>
<td>4.2445</td>
<td>2.952853</td>
</tr>
<tr>
<td>Vukovarska st.</td>
<td>0.784114</td>
<td>0.72218</td>
<td>6.530202</td>
<td>3.954004</td>
</tr>
<tr>
<td>Central axis**</td>
<td>0.752811</td>
<td>0.716057</td>
<td>5.337157</td>
<td>3.624651</td>
</tr>
<tr>
<td>Zagrebacka av.</td>
<td>0.757734</td>
<td>0.67180</td>
<td>4.570052</td>
<td>4.570052</td>
</tr>
</tbody>
</table>

Table 2 - Axial measurements for the city of Zagreb and its streets

The table 2 enables multiple comparisons. Firstly, we can compare linear parts of the cities (streets, pathways) with the entire urban system of Zagreb. Secondly, there is a comparison of those routes which have historical background from before 20th c. and planned axis introduced in the 20th c. (in the table: Vukovarska st., Central axis** and Zagrebacka av.). Thirdly, comparison is possible for the historical gateway-pathways between the form of its historical and contemporary route which appeared during urban growth and spreading of the urban fabric.

In the table the highest values are marked in red and the lowest in blue. Both historical gateway-pathways and analysed 20th century arterial streets in the table 3 show similar characteristics when compared to the whole urban network: high maximum values of Integration HH – very

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12 Ilica cont.* = Ilica contemporary gateway-pathway consists of Ilica street and Avenue Bologna; Vlaska cont.* = Vlaska contemporary gateway-pathway consists of Vlaska street, Maksimirka road and Avenue Dubrava - this pathway is historical and since the 2nd mil. survey its route layout was not transformed significantly (this is layout plan criteria for transformation; urban design and building structures were not considered here); Savska cont.* = Savska contemporary gateway-pathway consists of Frankopanska street, Savska road, Jadranski bridge and Jadranska avenue; Central axis ** = axis that evolved through Zagreb regulations (fig. 2).
close or the same as maximum in the system (taking into consideration the whole system = Rn) and above the system average mean values for all measurements – Integration HH, Integration HH R2 and Connectivity. This confirms the fact that those streets are significant in the whole urban network, but does not give clear answers to questions on how or why.

All three historical gateway-pathways have lower mean values both for integration and connectivity. This is not surprising since here we characterised the historical routes based on what was preserved in the contemporary axial map. More interesting is the fact that maximum values are the same for the historical and contemporary selections, which means that the new areas appearing in contemporary routes have not increased the syntactic values. This brings us to the potential inquiries for future research: specifically, to the question whether the results would be the same if we compared different segments across the city for streets with and without historical background, and whether, in that way, we can detect heritage and historical layers.

To elaborate the table further within the context of explained gateway-pathway typologies we can consider connectivity. Two streets which significantly transformed their routes and characters in contemporary urban network are Petrinjska and Savska pathways. They both have marked differences between the mean connectivity value from historical route selections and new route selections. Vlaska has null difference because its transformation preserved the route continuity while Ilica had two significant breaks by the railway line but still its character remained parallel to the railway on the north and south, with the difference below 1. For these observations to be meaningful, further comparisons with other streets within network are needed, or even a comparison with gateway-pathway transformations found in other cities.

5. TESTING HISTORICAL GATEWAY-PATHWAY TYPOLOGY THROUGH TRANSECT METHOD

To obtain a deeper insight into networks of historical gateway-pathways all of them were compared in transect method. Since the historical gateway-pathways were defined as the pathways which used to lead from periphery into the historical urban core we decided to compare transect overlaps with the 10% integration core and overall network to see if there are syntactical differences.

2-step transects were made for all four analysed historical pathways (Ilica, Vlaska, Savska and Petrinjska pathways). Transects represent the historical route and its immediate surroundings on the contemporary map (black in fig. 6 and 7). In figure 8 the traces of the historical gateway-pathway on the contemporary map or zero step-depth axial lines are marked in black while the immediate surrounding streets (axial lines which are 1-step and 2-steps away from the selected traces of gateway-pathway) are marked in grey.

In this way, the transect comparison involves information about both the initial historical situation and the transformation processes during urban growth because we selected trances of historical (original) route from contemporary model.

‘Visual-graphical descriptive’ analyses of the transects and the superimposed 10% integration core on figures 6 and 7 reveal important characteristics of gateway-pathways. Combining transects integration core form is recognisable. This overlap includes 472 lines out of 1324 (fig. 6 and 7). Therefore, 36% of the axial lines comprising the 10% integration core of the Zagreb contemporary street network are lines that belong to historical gateway-pathways (black lines in image 6 and 7) and immediately adjacent streets (up to two steps away from the gateway-pathway – grey lines in image 6-8). This could indicate that the city’s growth happened along these lines and that they are distinctive in the overall urban network which is a basis for forming a syntactic gateway-pathway definition.
Further, if we look at transects individually (fig. 8), already by ‘visual-graphical descriptive’ comparison, there are differences in percentage of pattern overlaps (red line shows 2-step transect lines which also belong to the 10% integration core). By the amount of red overlaps Petrinjska pathway (no. 4) is quite different from others and this method seems enough to detect the disappeared typology of gateway-pathways, which was transformed with significant breaks in its route layouts and therefore is incorporated into urban fabric of the city by urban growth. Pathway Ilica (no. 1) also is another extreme from these four but not in correlation with the typology identification and therefore numerical analysis is done in table 3.
This table 3 presents four observed pathways in four columns with four groups of information (table rows): 1) numbers of lines, 2) overlap percentages, 3) values for integration and 4) connectivity. In order to interpret results from the table 3, the percentages are compared with data from table 4, which is a summary for four gateway-pathways of Zagreb through the number and character of the breaks in continuity of historical route. Breaks are important for analysing the changes through time because they are the evidence of ‘historical incidents’ in urban growth.

Vlaska pathway is the 2-step transect with the biggest in the number of axial lines, Ilica follows, then Savska and Petrinjska. Petrinjska as disappeared gateway type expectedly has the smallest number of lines in 2-step transect, while Ilica and Vlaska show quite similar number of lines, but the overlap percentages and other data shows differences although in the typological identification they are the same type.

Numbers of lines are given for the:
- Step 0 (zero) = selected lines in Depthmap program for step depth calculation;
- step 1 = one step away axial lines from selected;
- step 2 = all two step away axial lines from selected

Overlaps are the percentage interpretations of numerical data of counting lines. The first overlap shows how much of the pathway transect is a part of the 10% integration core calculated by dividing number of overlapped lines with total number of transect lines.

The second overlap is how much of the integration core is occupied by the gateway-pathway. This is calculated by dividing number of overlapped lines form each transect with total number of lines in integration core which is 1324.

The third percentage overlap gives the relation between the transects and the city of Zagreb as information of how much of the overall city is occupied by transect which is calculated by dividing total number of transect lines with total size of Zagreb axial map which is 13236.
### Historical Pathways transect system

<table>
<thead>
<tr>
<th></th>
<th>Ilica</th>
<th>Vlaska</th>
<th>Savska</th>
<th>Petrinjska</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lines:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N Total</td>
<td>355</td>
<td>390</td>
<td>305</td>
<td>186</td>
</tr>
<tr>
<td>N step depth 0</td>
<td>29</td>
<td>16</td>
<td>25</td>
<td>9</td>
</tr>
<tr>
<td>N step depth 1</td>
<td>116</td>
<td>106</td>
<td>85</td>
<td>45</td>
</tr>
<tr>
<td>N step depth 2</td>
<td>210</td>
<td>268</td>
<td>195</td>
<td>132</td>
</tr>
<tr>
<td>N overlapped lines with 10% integration core</td>
<td>88</td>
<td>162</td>
<td>205</td>
<td>138</td>
</tr>
</tbody>
</table>

#### Overlap percentage:

<table>
<thead>
<tr>
<th></th>
<th>Ilica</th>
<th>Vlaska</th>
<th>Savska</th>
<th>Petrinjska</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of historical pathway transects that overlaps with 10% integration core</td>
<td>24.79%</td>
<td>41.54%</td>
<td>67.21%</td>
<td>74.19%</td>
</tr>
<tr>
<td>N overlapped / N total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of overlapped lines in the 10% integration coreN overlapped / 1324 lines</td>
<td>6.65%</td>
<td>12.24%</td>
<td>15.48%</td>
<td>10.42%</td>
</tr>
<tr>
<td>% of overlapped lines in overall city network N total / 13236 lines</td>
<td>2.68%</td>
<td>2.95%</td>
<td>2.30%</td>
<td>1.41%</td>
</tr>
</tbody>
</table>

#### Integration HH:

<table>
<thead>
<tr>
<th></th>
<th>Ilica</th>
<th>Vlaska</th>
<th>Savska</th>
<th>Petrinjska</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rn MAX</td>
<td>0.777606</td>
<td>0.770287</td>
<td>0.784114</td>
<td>0.784114</td>
</tr>
<tr>
<td>Rn MEAN</td>
<td>0.564767</td>
<td>0.613456</td>
<td>0.651852</td>
<td>0.686311</td>
</tr>
<tr>
<td>R2 MAX</td>
<td>6.742888</td>
<td>7.315790</td>
<td>6.742888</td>
<td>6.742888</td>
</tr>
<tr>
<td>R2 MEAN</td>
<td>2.225436</td>
<td>2.548053</td>
<td>2.653397</td>
<td>2.799870</td>
</tr>
</tbody>
</table>

#### Connectivity:

<table>
<thead>
<tr>
<th></th>
<th>Ilica</th>
<th>Vlaska</th>
<th>Savska</th>
<th>Petrinjska</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX</td>
<td>47</td>
<td>26</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>MEAN</td>
<td>3.909859</td>
<td>4.474359</td>
<td>4.295082</td>
<td>5.016129</td>
</tr>
</tbody>
</table>

Table 3 - Axial syntactical profile of the historical gateway pathways two step depth transects.

### Historical Pathways transect system

<table>
<thead>
<tr>
<th></th>
<th>Ilica</th>
<th>Vlaska</th>
<th>Savska</th>
<th>Petrinjska</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stretching of the zero-step-depth selection</td>
<td>East-west connection (from the main square to east)</td>
<td>East-west connection (from the main square to west)</td>
<td>North-south diagonal connection (east from central urban axis)</td>
<td>North-south diagonal connection (first street to the west of central axis)</td>
</tr>
<tr>
<td>Number of breaks in zero-step-depth lines and continuity:</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Reasons for the breaks:</td>
<td>railway</td>
<td>Bridge; elevated roundabout</td>
<td>Rail and Historical transformation of the route; railway main station placement with industrial area; and east-west dominant streets connections from regulation in 1953</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 - Comparison in the transect breaks at zero-step-depth selections of historical gateway-pathways from overlapping in ArcMap georeferenced historical maps and transects.
The two north-south connections – Sava and Petrinjska – both have the highest values for integration (0.784114) and connectivity (47), which are due to presence of Vukovarska east-west street in their 2-step transect networks (from the table 2 we can see that Vukovarska has the highest values in the overall Zagreb axial lines). Differences between Savska and Petrinjska 2-step transects are in percentages. Petrinjska occupies only 1.41% of the overall city network, but with the high percentage of lines (74.19%) being a part of the integration core and having in mind that this high number is still reveals only 10.42% of the integration core lines. All this together additionally confirms typological identification for Petrinjska. The reasons for this are listed in the table 4, where Petrinjska pathway is with the highest number of breaks in the continuity of its historical route.

The Savska transect shows that more than a half of the transect lines are a part of 10% integration core with 15.48% out of integration core from overlapping lines as the biggest percentage in this category. The percentage of overlap with the overall urban network is 2.3%, which may indicate that Savska remained important as a gateway. The two breaks in the continuity of Savska historical route and descriptive analysis of this pathway no. 3 in the figure 8 shows that a ‘historical incident’ happened causing the split of Savska gateway-pathway – this was the new traffic regulation with new bridge position across the Sava and redirection to form a different gateway system – motorway as the south-west regional entrance to the city of Zagreb. The comparison and value in differences between measurements of historical and contemporary selection in the table 2 confirm that this redirection caused significant difference in the role of two parts of original historical route for the city.

Vlaska and Ilica transects are identified as the same type according to the placement in the topography and transformation processes. They are east-west continuity line through main city square with partially irregular linear characters and mixed used shopping areas. The space syntax comparison shows hidden differences, although the numbers in the table 2 are quite close in values for the contemporary selection. According to the placement in topography they are both boarders between hill slopes of Medvenica and Sava river plain, but Ilica street leads to west and Vlaska to east from the main square. Vlaska is parallel and distanced from the railway while Ilica has two crossings with the railway. Therefore, Ilica had two breaks in the continuity of historical route and Vlaska is the only gateway-pathway in Zagreb without breaks in continuity.

The observed gateway-pathways are those which were classified as ‘transit gateway-pathways’ which led into historical core but outside of the walled part(s). The integration core should be in the place where dominating historical pathways used to lead into because it was the crossroad where the city developed through the growth process in 19th and later 20th century. Space syntax approach shows a possible way to test typologies numerically (as showed on Petrinjska), but more than that it gives us the way to perceive better differences in the same typologies (as showed on Ilica and Vlaska).

6. CONCLUSIONS AND NEXT STEPS

As a part of an on-going PhD research and research project, the paper gives insights into the syntactical description of Zagreb city and the methodological points for testing and developing a typological definition of ‘gateway-pathways’ in the context of urban growth studied on contemporary axial map. The heritage notion, which is explored through the analyses of Hillier’s transect method and star model, becomes measurable value which could lead in further exploration into route preservation and urban matrix criteria in planning the urban networks.

Methodology and presented results in this paper partially answer the two research questions investigated, which means that the study sets the basis for future research. Results of gateway-pathways comparison in Zagreb (tab.2) show that the selection process, of choosing axial lines for the transects, is a way of decoding historical layers in contemporary syntactical model. Transect analysis and comparisons were applied in GIS software. It is worth to further explore this transect comparison method (summarised in table 2) by adding more street examples. Also, regarding the second question related to testing the typological identification, to draw conclusions it is crucial to apply comparisons of streets on other cities. The percentage of
overlaps with 10% of most integrated axial lines in the city systems clearly shows types of gateway-pathways which stopped being entrances or connections to the periphery due to significant breaks in continuity. For the Zagreb case study, this is also another way of showing the change in local grid conditions. This ‘disappeared gateway’ type over time became fully part of the integration core of the city, which is one of the ways we can look at the centrality problematics.

Overall, this paper identifies an important link between urban heritage studies and space syntax theory. Space syntax enables an active understanding of spatial heritage in terms of historical processes, while transect analysis introduced in the paper opens new methodological prospects for historical studies of street networks.
REFERENCES


THE EVERYDAY AND THE POST-DISASTER URBAN SYSTEMS AS ONE THING
A configurational approach to enhance the recovery and resilience of cities affected by tsunamis.

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ABSTRACT
Tsunamis, despite occurring with low frequency, are permanent hazards for a large number of coastal cities and their consequences are highly devastating in terms of human losses, material damages and urban structure disruptions. It is argued in this paper that the urban structure not only has to be recovered after the tsunami event, but also has to provide an important basis for the continuing activities of the city, playing a fundamental role in the resilience of the whole urban system. By adopting a spatio-configurational approach based on space syntax theories and techniques, this research focuses on the dynamics of urban structures in relation to the different scenarios that tsunami-prone cities must face. The urban resilience process in both soon-after tsunami and post-tsunami scenarios is analysed using a Chilean coastal city located in a seismically active region as case study. The resilience capacity of the city in a soon-after tsunami situation is studied focusing on the influence of the urban layout in the route-finding decision makings during the evacuation process. The analysis reveals a weak correspondence between the existing evacuation plan and natural movement patterns, affecting the process of evacuation-route identification and the capacity to rapidly react to the threat. Additionally, the urban resilience in a post-disaster scenario is analysed regarding the ability of the city to maintain the basic functions and structures in order to be able to recover from tsunami impacts. The findings reveal important disruptions in the urban system’s spatial organisation, affecting the distribution of urban centralities and changing the operating patterns of the city after tsunami events. From this, the paper develops a comprehensive understanding of the different phases of the tsunami-prone city from a configurational approach, laying the foundations for evidence-based strategic proposals to enhance urban resilience capacity.

KEYWORDS
Tsunami-prone cities, urban resilience, evacuation process, Space Syntax.
1. INTRODUCTION

A large number of urban settlements are exposed to natural hazards, such as earthquakes, coastal erosion, volcanic eruption, cyclonic storms, floods and tsunamis. These extreme events could cause devastation, resulting in a loss of human lives, great environmental damage, and a partial or total loss of infrastructure (Ismail-Zadeh, 2014). Tsunami events are considered as one of the world’s most destructive natural hazards (Kulikov, et al 2005), and the impacts on the urban infrastructure could be devastating. As a consequence, the disruption of the urban system could modify the structure and functioning of the everyday city.

In the context of post-disaster condition, it is important to understand that the built environment not only has to be recovered, but also it has to support the rapid restoration of the everyday life (Allen, et al 2013). Therefore, the research identifies that there is a need not only for studying the impacts of the disaster on the built environment, but also for understanding how the built environment is able to cope with the negative effects of the disaster so as to return to a normal condition. The paper focuses on the analysis of the relationship between the structure and operation of everyday cities and their behaviour in disaster situations, recognising the importance of the existing structure and its role in the resilience process in both soon-after tsunami and in post-tsunami scenarios.

In the soon-after tsunami situation, the urban resilience is related to the capacity of the urban system to influence the returning to a prompt safety condition. The appropriate decisions about evacuation process could be a key factor to minimise the social impacts, the loss of human lives and the chaotic behaviours (March and Leon, 2015). Therefore, the analysis focuses on understanding the influence of the existing built environment in the evacuation process and the efficient route-finding decision-makings, which enable the population exposed to tsunami-waves to evacuate the risk area through an autonomous and effective process immediately after the tsunami. On the other hand, in the post-disaster scenario, the resilience is related to the capacity of the affected systems to restore their normal condition, maintaining the basic urban operations and social economic functions. Therefore, it is very important to explore the performance of the urban system after being impacted or modified by the disaster. The analysis focuses on the principal changes in spatial and functional aspects, comparing the urban structures, activities and spatial properties of the everyday and post-disaster city.

1.1 THE SOON-AFTER TSUNAMI CITY: RESILIENCE AND EVACUATION PROCESS.

Since tsunamis are suddenly generated events, there is little warning time before they strike (IOC-UNESCO, 2008), giving not enough time to the population to react opportunely and take critical decisions. This is why the evacuation process often needs to be self-initiated and autonomously conducted by people (Schmidtlein and Wood, 2014). It has been argued that in these situations of chaos, during the evacuation people face problems in the route-finding decisions making, and as a consequence the evacuees tend to use the recognisable and known paths as potential evacuation routes (Proulx, 2001 and Mohareb, 2011). Since people’s evacuation behaviour has been closely related to the normal patterns of circulation (Kimura and Sime, 1989), the concept of wayfinding applied in the everyday situations could be associated with the wayfinding in emergency conditions, in order to understand the possible people’s route-finding decisions during the evacuation.

It has been demonstrated through experimental evidence that the individual spatial decision-making in the wayfinding behaviour is strongly affected by the spatial configuration of the built environment (Emo et al, 2012). In this context, Space syntax theories have sought to understand the way in which pedestrians move around their environment, demonstrating through the theory of the “natural movement” (Hillier and Penn 1993) that the configuration of the street network is itself a primary generator of pedestrian movement patterns. This argument becomes a critical issue when analysing the behaviour of people during the emergency and selecting the factors that influence their wayfinding from a spatial perspective.
Considering the strong correlation between observed movement flows and space syntax measures (Hillier and Iida, 2005), it is argued in this research, that the spatial structure of tsunami-prone cities could be analysed configurationally in order to identify the paths that are more likely to be selected in the everyday life. This, allows to highlight the more familiar routes, which as it has been pointed out, are more likely to be selected when evacuating the city’s exposed area.

1.2 THE POST-TSUNAMI CITY: RESILIENCE AND URBAN FUNCTIONING.

Besides the human losses, tsunamis generate serious impacts on residential areas and urban systems (Moris and Walker, 2015). Along with this, the impact of the tsunami generates disruptions on the urban structure’s functioning, seriously damaging roads and bridges, which affects the connectivity and accessibility of areas and disables the normal use of the urban structure of the city. In this context, it has been argued that after the disaster, the city’s urban structure provides an important basis for the continuing activities of the city, playing a fundamental role in the resilience of the whole urban system (Allan, et al 2013). Understanding how the flood of potential tsunamis will affect the cities and how the city structure will behave, becomes a basis for the planning of coastal settlements and the design of mitigation strategies.

It has been consistently demonstrated that the built environment’s spatial structure is intimately connected to how cities function and how they are used by people (Hillier, 1999). The configurational approach of space syntax theory has allowed to identify a strong correlation between spatial patterns, human movement and the socio-economic processes in cities. It has been proved that the impact of spatial configuration on movement and its subsequent influence on land uses location plays a critical role in the formation of urban centralities (Hillier, 1999b) and the distribution of commercial areas and residential functions (Hillier and Penn 1993). From this perspective, the important role of spatial configurational analysis as a means to understand the functioning and operation of cities represents a significant tool to evaluate the impact on the urban grid patterns caused by the tsunami flood in extensive parts of the cities.

2. DATASETS AND METHODS

For this study Viña del Mar city located in the central area of Chile has been selected as a case study. The main reasons that support the selection of this city are related to: its location in one of the most seismically active regions of the world and one of the main areas that generate tsunamis (Lagos and Cisternas, 2008), the frequency of tsunami events throughout history and the demographic characteristics.

A multi-scenario approach (Figure1) is proposed in this study to conduct a syntactical analysis of the city and construct an evidence-based understanding of the urban structure’s role in tsunami events. The first studied scenario is the “Everyday City”, which is the initial urban system before the occurrence of the natural event. This stage is focused on the understanding of the structure and functioning of the pre-tsunami city, based on the analysis of the spatial properties and the distribution of urban centralities.
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The second studied scenario is the “Soon-after Tsunami City”, which is considered as the exposed system, or the area that has to be evacuated soon-after the generation of a tsunami. This scenario is defined to evaluate the evacuation process which is considered as the most effective method to reduce the possibility of being directly affected by the tsunami. To determine the exposed area, the evacuation maps produced by ONEMI (the Chilean National Emergency Office) are used. These maps identify the exposed areas, the evacuation routes and the limit of the safe zones. The syntactical “Choice” measure is used to understand people’s route-finding decisions during the evacuation. Choice values correspond to the segments’ potential movement flows of “through-movement”, forecasting which routes are more likely to be selected as shortest paths from all spaces to all other spaces in the system (Hillier et al, 1987). As explained previously, people’s evacuation behaviour is closely related to the normal patterns of circulation, so the highest Choice values of the “everyday city system” are considered in order to comprehend the patterns of natural evacuation wayfinding.

The third scenario is the “Post-tsunami City”, which is defined as the possible affected system that has been disturbed because of the destruction of the urban infrastructure or the creation of non-accessible zones. To determine the possible affected areas, the Tsunami Inundation Maps for the Chilean Coast produced by SHOA (The Hydrographic and Oceanographic Service of the Chilean Navy) are used. A spatio-functional method of analysis is proposed using the “Integration” analysis to investigate the changes in the urban configuration after the tsunami, being possible to visualise the potential distribution of destination movements and point out the spatial dimension of urban centralities (Hillier, 1999). Centrality is a process with both spatial and functional aspects, therefore an analysis of the operational systems is carried out by studying land use distribution, in order to understand how configurational and functional dynamics of cities are interrelated. The changes on the spatial organisation before and after tsunami perturbations are the measures to understand the impact on the functioning of the city and the distribution of main urban centralities after the event.

3. RESULTS

3.1 SOON-AFTER TSUNAMI ANALYSIS, EVACUATION PROCESS.

The exposed area to be potentially flooded by the tsunami corresponds to the 32.69% of the total street segments’ length. Practically all the areas located on the plains should be evacuated, while the ones on the hills are within the safety zone.

A normalized global Choice(NACH n) analysis of the “Everyday-city” scenario is introduced in order to pick out the streets which are more familiar to evacuees in daily life and as a consequence are likely to be selected during evacuation soon-after the generation of tsunamis (Figure 2). The 20% highest Choice represents the routes with more potentials to be selected. It is possible to distinguish a network which connects the city in north-south and east-west. The average NACH n values of the 20% principal routes of the system is 1.30 which is significantly higher than the NACH 1.03 of the evacuation routes. By overlapping the evacuation routes with the 20% highest Choice values, it is found that only 24.6% of the two sets of lines match (Figure 2). Based on this, it is possible to argue that the designated routes for evacuation are not strongly associated with the natural movement patterns of the everyday-life.
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Figure 2 - Relationship between natural movement and existing evacuation routes. (Up: normalised Choice analysis, Down: correspondence between existing evacuation plan and 20% highest NACH segments.)
Based on metric step-depth analysis (Figure 3), which measures the distances to reach all segments in the network from an indicated origin, the segments that could be evacuated on time are studied using the evacuation limit as a destination and all exposed segments as origins. To determine the appropriate time for evacuation, the ONEMI’s recommendation for Chilean cites of 15 minutes in a speed of human walking is considered (ONEMI, 2014). The moderate walk speed of 1.22 m/s is defined for the analysis. This analysis shows that about 9.15 % of the street segments could not be evacuated within 15 minutes at a moderate speed walk.

![Figure 3 - Evacuation time for segments based on metric distance to evacuation limits.](image)

<table>
<thead>
<tr>
<th>Exposed system segment length</th>
<th>Segment length not evacuated within 15 min</th>
<th>% Segment not evacuated within 15 min</th>
</tr>
</thead>
<tbody>
<tr>
<td>103,416 m</td>
<td>9,459</td>
<td>0.8187</td>
</tr>
</tbody>
</table>

After the full catchment analysis where the segments that have difficulty in being evacuated because of the distance to safe areas were identified, a differentiated catchment analysis is carried out to define the best route’s direction for evacuation depending on the destination. A catchment analysis from the different evacuation destinations, in this case northern and southern evacuation limits, is performed (Figure 4, Up).

As a result, the exposed area that should be evacuated to the northern limits, and the area that should evacuate to the southern limit are visualized. Comparing the direction of the evacuation routes with the catchment analysis, it is possible to observe that the directionality of 15.30% of the routes does not match with the catchment areas, therefore an important number of segments are being evacuated to the northern limit instead of evacuate to the south (Figure 4). It is possible to conclude that the current routes do not guarantee a safe evacuation since the whole exposed area cannot be evacuated in time.
Figure 4 - Areas not evacuated in time. (Up: correspondence between existing plan and catchment evacuation areas. Down: direction and distance of evacuation routes)
Since the evacuation process must be performed autonomously and in a short time, it is expected that the percentage of correspondence between the natural movement system and the evacuation routes increases in order to develop an evacuation plan that follows the logics of natural movement, reducing the problems in the route-finding decisions during the evacuation process. Strategic proposals are developed in order to decrease the evacuation times and simplify the route-finding process (Figure 5). These proposals seek to improve the process of resilience soon-after the tsunami generation, which is associated with the effective response to the disturbance in evacuation processes.

To define the evacuation routes, the proposal follows the configurational properties of the street network, considering the syntactic measures, the catchment areas defined by the proper time to reach the evacuation limits, and the physical characteristics of the routes. The main purpose is to generate evacuation systems structured by a network and not by disconnected routes, increasing the correspondence with natural movement patterns. Viña del Mar proposed evacuation plan shows an average NACH of 1.21 which compared with the 1.03 of the current plan reflects a major propensity to be selected as evacuation routes (Figure 5). This becomes clearer by measuring the correspondence of the proposed evacuation routes with the 20% top Choice values, showing a 51.06% which contrasts to the 24.6% of the previous plan. The direction of the routes is proposed following the logic of the catchment areas, providing better time responses.

![Figure 5 - Correspondence between proposed evacuation plan and 20% top NACH segments.](image-url)
3.2 POST-Tsunami Analysis, Urban Structure and Functioning.

In order to understand the configurational urban impact on a post-tsunami scenario, the syntactic properties of the current city pre-tsunami are analysed using the Integration measures to define the structure of the urban centralities (Figure 6). The global core of integration is located in the central area along the river as a point of convergence of the southern and northern parts of the city. The analysis also picks up another structural line which runs from north-south direction in the northern area. The affected city is defined based on the Tsunami Inundation Maps 4th flooding level. In these circumstances, the 8.69% of the segments are directly affected by the flood. This percentage is obtained by calculating the ratio of the total length of the system to the total length of the affected segments. By removing the segments directly affected by the 4th level of floods, a breakdown occurs in the structure of the city, fragmenting the whole system into two new systems and severing all connections between them. These two new configurational systems: superior system (SI1) and inferior system (SI2) are located on both sides of the river. These extreme morphological and configurational changes strongly impact the distribution of global centralities, and an important part of the global integrated core disappears for being directly affected by the flood.

![Figure 6 - Distribution of global centralities and accessibility before and after tsunami.](image)

<table>
<thead>
<tr>
<th>Average NAIN n</th>
<th>Pre-Disaster City</th>
<th>Post-Disaster City SI1</th>
<th>Post-Disaster City SI2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.476</td>
<td>1.162</td>
<td>0.376</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6 - Distribution of global centralities and accessibility before and after tsunami. (Up: normalised integration analysis pre-tsunami. Down: normalised integration analysis post-tsunami)
The new Integration averages of the affected systems differ from the pre-tsunami system’s average (0.476), while SI2 Integration values average decreases (0.376), the SI1 average increases (1.162). Despite this sharp increase, it is unwise to argue that the system SI1 is affected positively, because it is completely segregated from the rest of the whole system.

The outstanding effects on the total organization of the urban system change the whole pattern of global centralities dramatically (Figure 7). The percentage of the post-tsunami integration core which overlaps with the pre-tsunami city corresponds to a 43%. In the northern system, the global integration core shifts to the east presenting a linear structure, whereas the southern core maintains its location along the river. However, the dominant route of the SI2 core moves slightly to the south since the rest of the area is flooded by the tsunami.

On the other hand, from a functioning analytical approach, the land uses are analysed to understand their distribution and relation with spatial centralities. In the everyday city functioning, the retail activities show a strong dependence on the highest Integration values of the urban structure (Figure 8). The services follow the same pattern concentrating mainly around global centralities. The areas with lower Integration values mainly located on the hills, maintain a land use focused primarily on residential activities. The frontages of the 15% more globally integrated segments are studied observing that there is more than 50% of correspondence with non-residential uses, most of which belong to the retail sector. The functioning of the city in the post-tsunami scenario is modified, not only by the disabling or destruction of flooded buildings, but also by the change in the relationship between activities and structural centralities.

With regard to the relationship between active frontages and the 15% highest Integration values, it is possible to observe an increase in the percentage of residential uses, and decrease of active frontages with retail and services. Based on this, it is possible to conclude that after a tsunami, cities can be highly affected, not only in terms of the direct damage on the urban infrastructure, but also in regards the modification of the indirect impacted areas dynamics.
Figure 8 - Relationship between global centralities and land uses distribution. (Up: Correspondence between pre-tsunami 15% highest integrated routes and land uses. Down: Correspondence between post-tsunami 15% highest integrated routes and land uses.)
In the case of Viña del Mar the effects of tsunamis on the organization of the urban system, both in configurational and functional terms, could impact the socio-economic processes after the event, weakening the resilience capacity of cities. The disturbances in the syntactical patterns of the street network and the shifts of the urban centralities result in a weak correspondence between pre and post-tsunami integration cores, which affects the natural patterns of interrelation between the urban structure and the operational functions, hindering the maintenance of the basic functions of the city during the resilience process. There is a lower density of active frontages of services and retail activities along the new integration centralities, compared to the pre-tsunami situation. As a result, the new centralities show a greater dependence on residential land uses that does not coincide with the natural logics of urban centres, losing their economic significance. The most determinant changes in Viña del Mar are results of the fragmentation of the whole urban structure into two new unconnected systems. This disruption changes not only the syntax of its urban structure but also its operability as a total system, altering the spatial accessibilities and the connectivity of the street network.

Evidence-based proposals have been developed in order to improve the urban performance in the post-tsunami scenario (Figure 9). The main objective is to re-establish the patterns of functioning of the everyday city after a disaster, increasing the correspondence between pre and post-tsunami integration cores to maintain the basic operation and the structuring centralities. The two main actions are as follows:

3.2.1 ACTION (A1):
To ensure the operation of the structuring route in north-south direction, in order to maintain the functioning of the system as a whole. This action keeps the distribution of the structural centralities and also allows the distribution of mainly commercial activities along these centres.

3.2.2 ACTION (A2):
To connect east to west the two affected systems. This allows the population of the eastern areas to have accessibility to the services located in the centre of the city where the economic and administrative activities are concentrated.

The proposed actions allow the urban system to restore normal operating conditions to a higher extent compared to the post-tsunami situation. In the case of Viña del Mar is not possible to generate a comparison based on the new average Integration values due to the anomaly in the post-tsunami figures caused by the fragmentation of the system in two new systems. However, it is possible to argue that the new values are very similar to the ones in everyday city and a strong correlation between pre and the proposed post-tsunami scenarios is observed, going from 41% of correspondence to 64% with the proposal (Figure 9).
Figure 9 - Proposed actions and post-tsunami distribution of global centralities (Up: Proposed action and normalised Integration analysis. Down: Correspondence between global centralities of everyday and proposed post-tsunami scenarios.)

The Everyday and the Post-Disaster Urban Systems as One Thing
A configurational approach to enhance the recovery and resilience of cities affected by tsunamis.
4. CONCLUSIONS

4.1 INTEGRATED RESPONSE PLAN

The research has attempted to present a new approach to the concept of urban resilience by considering the configurational properties of the built environment. The applied methodology enables to understand the role of the built environment and the particular importance of the spatial configuration on the rapid-recovery and resilience processes. This configurational approach permits the development of an Integrated Response Plan that considers both the evacuation and the post-disaster conditions. An integrated response plan for the tsunami-prone cities could be a support platform for future planning decisions, allowing to prioritise actions and define what should be done before the tsunami (if they are indispensable for the evacuation system) and what could be generated immediately after the event (to allow post-tsunami operations).

It is possible to overlap strategic proposals for both the soon-after tsunami and post-tsunami scenarios, in order to understand the principal actions to be carried out to ensure a better response to disasters. For segments used in the evacuation, pre-disaster measures should be taken into account so as to maintain the proper condition of the routes and the buildings to prevent their collapse and obstructions. In the case of the segments that structure the post-event urban system, prior actions could be taken to allow immediate operation of the routes considering tsunami-resistant measures or to evaluate repair actions that allow the operation of the routes in the shortest time possible. This plan could be considered as an important tool for making urban design decisions, preventative strategies and repair actions.

Figure 10. Basis for the Integrated response plan for Viña del Mar.
4.2 FINAL COMMENTS

The concept of resilience related to natural disasters is very complex and needs to be evaluated from multiple viewpoints. In this research, the focus was on the role of the physical environment from the perspective of urban resilience. The main principles of the theory of space syntax and its methods of analysis were useful to develop an understanding of the role of the cities’ configuration in the process of enhancing resilience for both, the soon-after and post-tsunami scenarios.

In the case of soon-after scenarios, the configurational approach was used to investigate cognitive issues related to the role of urban structure during the evacuation, so as to understand the route-finding decision makings. Based on this analysis it is possible to conclude that current plans do not include configurational notions in the process of defining the evacuation routes. The existing plan does not form an interconnected system or a network of evacuation, but is only based on the determination of an origin and a destination without a greater understanding of the relationship between these routes and the whole system. Considering that the evacuation process must be performed autonomously, it is expected that the evacuation plan should take into account the logic of the natural movement based on the urban network configurational properties, in order to develop a rapid resilience capacity soon-after the generation of the tsunami, to rapidly react and cope with the threat.

In addition, it was possible to generate a study to deal with post-tsunami scenarios, where the configurational analysis was critical to understand not only the role of the area that is directly affected by the tsunami, but above all to assess the functioning of the system that is indirectly impacted by the disaster and should continue operating after the event. The indirect impacted area suffers disturbances in its system which are visible when generating syntactic measures. In this way, it was suggested to analyse and visualise how the wider impact of the tsunami on the urban street network modifies the system operation after the disaster and impacts the resilience capacity.

It is possible now to argue that even though there are different studies of tsunami affected cities, it is necessary to create an integrated understanding of the process of resilience, considering the analysis of soon-after and post-tsunami conditions from the configurational perspective, in order to generate an action plan consistent with the requirements of both phases. This could provide a guideline to local authorities to ensure that the pre and post-tsunami activities are seamlessly maintained. To understand that the analysis of the post-disaster situation should consider the analysis of the everyday scenario is fundamental to the development of projects that successfully respond to the post-disaster requirements as well as influencing the city planning for normal situations, improving day-to-day conditions.

Finally, as a further study it is proposed to incorporate into this model of analysis other variables that complement the study of the spatial configuration. Physical environment variables such as the level of maintenance of routes and buildings, the presence and location of the strategic urban functions and the location of the rescues, could be incorporated in order to have a more comprehensive understanding of the physical environment during disasters. It would also be important to consider population characteristics, which could contribute to the understanding of the communities to be evacuated, as well as their requirements for the further phases. Since this analysis was based on one of the riskiest scenarios, an analysis of each of the possible degrees of inundation is also recommendable to generate a plan able to respond efficiently to all needs.
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RELATION BETWEEN LANDSCAPE FACILITIES AND URBAN LOCATION IN THE SQUARES OF CAMOBI NEIGHBOURHOOD: A space syntax analysis

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ABSTRACT

This paper presents an empirical research grounded on the theory that the diversity of landscape facilities in squares of suburban neighbourhoods is related to their location in the urban grid. Differences in relative accessibility induce uneven infrastructure distribution in the urban space, including the squares and their landscape facilities. Public authorities’ disregards towards community demands for equipping leisure spaces and spontaneous popular initiatives to use existing but not equipped green spaces are remarkable social-spatial phenomena of local scope in Brazil. While some neighbourhood squares are merely highlighted in city maps, being barely furnished, others have more amenities, implemented through local dwellers demands. Based in the assumption that mixed co-presence patterns between inhabitants and strangers tend to weaken the spatial control of one category over another, the squares location could reduce or reinforce dwellers’ organization to claim for or implement improvements in public spaces. Therefore, the research problem is as follows: does these squares location have any relation to the degree of implanted landscape facilities diversity? Our hypothesis is that squares that have greater diversity of landscape facilities are located in areas within local dwellers’ domain and less accessible to strangers. Therefore, the aim in this work is to quantify the diversity of landscape facilities implemented in the studied area public squares, and analyse their location in terms of relative accessibility and strangers/inhabitants social categories movement potential in their surroundings. The research methodology consists of three steps: a) quantification of existent landscape facilities diversity in each square of the sample through systematic observation; b) relative accessibility and movement potential measurements through the syntactic measures of integration and choice; c) analysis of the statistical strength of the relationship among variables by calculating their correlation coefficients. The results indicate that where the presence of strangers is frequent, inhabitants reduce their organization to claim for or spontaneously implement improvements in the squares. Because we worked with a restricted sample of city’s squares, results are insufficient to validate the hypothesis. However, the moderate correlations seem a promising step in understanding the phenomenon.
1. INTRODUCTION

Different locations in the city have different relative accessibility, which imply in inducing uneven land parcels valorisation (Villaça, 2001). One of the effects of this dynamics is the uneven infrastructure distribution in the urban space, which includes the squares and their landscape facilities such as planting, paving, benches and others. Public authorities’ disregards towards community demands for equipping leisure spaces and spontaneous popular initiatives to use existing but not equipped green spaces (Kliass and Magnoli, 2006) are remarkable social-spatial phenomena of local scope in Brazil. Therefore, the research problem is as follows: does these squares location have any relation to the degree of implanted landscape facilities diversity? Our hypothesis is that squares that have greater diversity of landscape facilities are located in areas within local inhabitants’ domain and less accessible to strangers. Therefore, the aim of this work is to quantify the diversity of landscape facilities implemented in the studied area public squares, and analyse their location in terms of relative accessibility and strangers / inhabitants social categories movement potential in their surroundings.

2. MOVEMENT PATTERNS

Space Syntax theory on natural movement states that urban grid morphological properties inform and differentiate movement potentials along axial lines, configuring a probabilistic field of potential encounters between two social categories: inhabitants and strangers (Hillier et al., 1993). Strangers’ movement tends to be channelled towards lines with greater tendency to be used in global movements. Their access to any place within the settlement is mediated by adjacency between buildings and co-presence patterns in public spaces. On the other hand, inhabitants have a more pervasive control over the urban system, tending to establish static and local relationships. The more globally integrated the urban system is, the greater the tendency of mixed co-presence between inhabitants and strangers by even control over the spatial system (Hillier and Hanson, 1984). To analyse movement potential in the urban grid, we must consider both to-movement and through-movement, which correlate, respectively, with the syntactic measures of integration and choice (Hillier and Vaughan, 2007). In order to better predict pedestrian movement, we must restrict the calculation of measures to a certain number of depth steps, usually three or five (Hillier, 2007).

3. THE STUDY AREA

The study area is the Camobi neighbourhood, located in the eastern outskirts of Santa Maria city, Brazil (Figure 1). Although it is the city’s largest residential neighbourhood in terms of territorial extension (20.35 km²) and absolute population (21,822 inhabitants), it is characterized by low demographic and built densities. Camobi has the largest absolute amount of public squares in the city (seven out of a total of fifty), but some of them are merely assigned in the urban plan, consisting of urban voids. On the other hand, there are two squares which landscape facilities were improved by local inhabitants, that raise an interesting question of a possible relation between these squares location and patterns of mixed co-presence in public spaces.
4. METHODOLOGY

The research methodology consists of three steps. First, existent diversity of landscape facilities was quantified in each square of the sample through systematic observation. For the purpose of simplification, landscape facilities types were classified in five categories, based on the open space survey tables of Pippi et al. (2011) as follow: paving; equipment; furniture; planting and seedlings. Each existing item was framed into one of these categories and scored, regardless its quantity, since the squares surface areas vary, disposing different facilities capacities. For example, one point for all existing benches. Then, movement potential was measured by syntactic measures of integration and choice, obtained from axial map (Salamoni, 2008) through the depthmapX0.30 (Figure 2). All variables were normalized in a range of 0 to 1 for the analysis (Figure 3). Finally, the Pearson correlation coefficients between each syntactic measures and landscape facilities scores were calculated in order to obtain the statistical strength of the relationship among variables.

5. RESULTS

Regarding the integration measure, it was verified that almost all squares have their values of local integration R3 and R5 close to the system global measure (Rn). Therefore, almost all squares have access and control by both categories of person: strangers and inhabitants. When such potential for mixed co-presence, the tendency is to weaken the control of one category over another and, perhaps, to weaken the territoriality of residents over the squares, reducing their organization to claim for or implement improvements in the squares. Poet’s square has the lowest global and local integration values and, therefore, is less accessible to strangers, displaying the second highest score of landscape facilities. All other squares, located along axial lines where local integration is close to the system maximum (global), have the lowest scores of landscape facilities.
In relation to the measures of choice $R_n$, $R_3$ and $R_5$, practically all squares have values near to the minimum of the system. Therefore, it reduces their probability of receiving global and local flows. As an exception, the Ademar Cantarelli square holds the highest values of choice ($R_n$, $R_3$ and $R_5$) and the lowest score of landscape facilities. On the other hand, two squares with the highest scores of landscape facilities have the lowest values of choice ($R_n$, $R_3$ and $R_5$).

The correlations between the variable landscape facilities versus each syntactic measure indicate a negative tendency: high values of integration and choice ($R_n$, $R_3$ and $R_5$) tend to correspond to low scores of landscape facilities in the considered sample. However, an interesting point observed in the case of Ademar Cantarelli square - the lowest score of landscape facilities - is that both integration and choice measures ($R_n$, $R_3$ and $R_5$) are the highest of the sample. We verified a reverse behaviour for Poet’s square, which holds the second highest landscape facilities score and the lowest values for the integration as well as choice ($R_n$, $R_3$ and $R_5$) measures. The behaviour of the landscape facilities variable seemed to be more sensitive to integration and choice variables ($R_n$, $R_3$ and $R_5$) performance, simultaneously, at their maximum or minimum values. The Pearson correlation coefficients were calculated between the landscape facilities scores and each of the syntactic measures as follow: -0.4485 (integration $R_n$); -0.6733 (integration $R_3$); -0.5612 (integration $R_5$); -0.4647 (choice $R_n$); -0.5448 (choice $R_3$) and -0.4656 (choice $R_5$). The measure of integration $R_3$ would have a higher association degree with the landscape facilities and statistically, all obtained correlations are of moderated robustness.
RELATION BETWEEN LANDSCAPE FACILITIES AND URBAN LOCATION IN THE SQUARES OF CAMOBI NEIGHBOURHOOD: A space syntax analysis

Figure 2 - Axial maps of Camobi with the syntactic measures obtained.
6. CONCLUSIONS

The Camobi neighbourhood squares have good relative accessibility, at global and local levels, and their locations increase possibilities for mixed co-presence between inhabitants and strangers, creating a tendency to weaken the spatial control of one social category over the other. Thus, where the presence of strangers is frequent, inhabitants seem to not implement improvements in the squares. Analysing this phenomenon would also imply checking the influence of other used variables related to squares location that space syntax fails to capture, such as the hierarchy of its adjacent pathways. Likewise, Ademar Cantarelli and Poet’s squares display differences in these characteristics. It is known that high speed motorized transit – highways - represents a risk to safety and leisure of potential square users, reducing the concern of inhabitants in controlling this space. On the contrary, local low speed transit tends to encourage the appropriation of public spaces as an extension of private spaces.

For the sample taken, analysis performed depicted opposite situations in which landscape facilities are better. Where global measures are higher, high movement potentials and shared spatial control between inhabitants and strangers, close to axial lines in which vehicular flows probability through the urban grid are high; or, where global and local measures are the lowest for the sample, informing low movement potentials and inhabitants spatial control, where flows through the neighbourhood are expected to be low.
The slightly robust correlation between facilities and local measures indicate that most of the squares depicted in the sample, are due to be socially appropriated by neighbouring dwellers as an extension of their private space/household. Nevertheless, Camobi is a low built density neighbourhood, where suburban land developments abound. Therefore, the tendency to neglect public space segregated from axial lines where vehicular movement potentials and flows probabilities inform the emergence of functional centralities. The other extreme presupposes some kind of community organization at very local scale, where control over space exerted by neighbours incorporate the public square into the realm of privatized spaces denoting that segregation at local and global scales incite particular ways of spatial governance. The way in which social appropriation of the square space is driven by neighbours demands. Once the modest size of the sample analysed and the peculiarities of the neighbourhood where they are all located, results achieved are insufficient to confirm our initial hypothesis. Therefore, a wider and diversified sample is required for further and more accurate analysis of such phenomenon.
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PIPA BEYOND THE RING: Exploring possible effects of a road grid expansion on the centrality of a coastal resort

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ABSTRACT
The proposed paper addresses relations between space configuration and centrality in a coastal resort, in diachronic perspective (2006 and 2013), in order to evaluate the interference of addition of new road stretches, outlining a ringy conformation, in the accessibility of the resort’s main thoroughfare, a point of convergence of pedestrian movement, function diversity and sociocultural animation.

The focus in this paper is to present the spatial properties defining and supporting that centrality, to discuss how such properties appear to have been only minimally affected by the recent road development, and to forward some conjectures about its possible after-effects, concerning the formation of new centralities, stemming from the ideas of centrality as a process (Hillier, 1999).

Pipa is a trendy holiday destination, is the hearth of a coastal resort situated in the Northeast Region of Brazil, which grew from a fishing village, developing into a deformed grid that conforms to its sloped natural site. Its main thoroughfare, Avenida Baia dos Golfinhos, is partly pedestrianized, is seen as an iconic image of Pipa, sharing status with views of its many bays and cliffs, running parallel to the sea, some between 30m and 100m uphill, is the longest street, with a section that concentrates a mix of land uses and activities housed in narrow blocks.

The results show that the topological hierarchy is maintained after changes in the road grid, the strong linear centrality anchored in Avenida Baia dos Golfinhos is also sustained. The centrality continues its process, considering that the animation tends to concentrate in the shorter segments and shorter distance between blocks. On the other hand, the linear growth of the settlement southward is generating seems to anticipate the formation of centralities more likely to relate to vehicular movement.

The proposed paper research is part of an ongoing dissertation, whose aim is to investigate how and to what extent changes in the spatial structure of the coastal village of Pipa may affect urban qualities, which, together with privileged natural traits, confer identity to the place and render it unique.

KEYWORDS
Centrality, space configuration, Pipa village, coastal settlement
1. INTRODUCTION

The research reported here – part of an ongoing master dissertation – explores relations between space configuration and centrality, focusing on properties deemed indicative of movement, function diversity, and sociocultural animation, in diachronic perspective. Spatial properties vis-à-vis the presence of diverse land uses (and users) are examined within a seven-year temporal break (2006 and 2013) in a coastal resort renowned for its natural beauty that combined to the cultural flavours related to its long-term residents, and to a certain cosmopolitan air brought in by newcomers and visitors, confer the place unique qualities of urbanity. The study was motivated by the worry that the addition of new road stretches, outlining a ringy conformation that encompasses and encircles the area where most diversity and liveliness is concentrated, would impact the settlement’s hierarchy of topological accessibility and dilute the vitality of that area. The focus in this paper is, therefore, to present the spatial properties that we believe to have been crucial for defining and supporting that centrality, to discuss how such properties appear to have been only minimally affected by the recent road development, and to forward some conjectures about its possible after-effects, concerning the formation of new centralities.

Pipa, originally a fishing village, is the heart of a large coastal resort extent situated in the state of Rio Grande do Norte, Northeast Region of Brazil. There are references to fishing activity there since round 1800 (Simonetti, 2015). It was also a viable stop for vessels transporting merchandise to and from harbours in Rio Grande do Norte and Pernambuco. Besides Pipa, the districts of Piau, Cabaceiras and other minor settlements are part of Tibau do Sul, the present seat of a municipality, which grew independent from the town of Goianinha in the 1960s. South of Pipa and closely linked to its tourism and leisure compound is the district of Sibauma, part of the municipality of Canguaretama, which together with that of Goianinha comprise the southernmost coastal border of the state of Rio Grande do Norte, whose beaches are sought for as leisure resorts all year round.

Until recently, Pipa was connected by roads to the settlements of Tibau do Sul (north), Piau (west) and Sibauma (south). The road work built from 2008 through 2010, created a new link, to the settlement of Cabaceiras (figure 1), offering a shortcut to the road from Goianinha to Tibau do Sul, improved the route to Sibauma, by paving a third of the length of a difficult sandy track, and generated a circular circuit round Pipa’s urban centre, of which the main thoroughfare is the Avenida Baia dos Golfinhos running parallel to the sea, about 30m to 100m uphill from the water line. It is the longest street in Pipa, and it was the first land connection to Goianinha and to Tibau do Sul. The busy Avenida Baia dos Golfinhos is a well-known tourist destination and an icon of the "village" (a term often used to refer to Pipa that we shall adopt here), as it concentrates a variety of uses, mainly retail shops and restaurants that remain open till late, attracting hordes of passers-by, especially from late afternoon onward. This street can be considered the functional centre within the village’s street grid, which has grown from it, branching into paths and alleyways that define a deformed grid whose assemblage of connected lines compacts into a convex shape with lines that connect out into the surrounding area in the like of Hillier’s (1999, p. 118) "spiky potato" (figure 1).
PIPA BEYOND THE RING: Exploring possible effects of a road grid expansion on the centrality of a coastal resort

The new road construction widens some existing thoroughfares and creates broad roads stretches connecting them, so that a ring is formed, linking the two ends of Avenida Baia dos Golfinhos (Figure 1). As part of the road works, the access from Pipa to the beaches in the south was duplicated and paved and a short-cut was created connecting the southeast end of the Avenida to the zig-zagging way that leads to the entrance to the village. The ring is at present used as a round one-way circuit, running clockwise in and out of Pipa. The shortcut has greatly reduced the in and out distance for vehicular movement, especially that of touring coaches that take visitors around the area.

This road development induced our initial hypothesis that the ring could weaken the linear centrality of the village by diluting the movement concentrated in the Avenida, besides favouring land occupation to the South of Pipa that could lead to the formation of new centralities. In Figure 1, it is possible to note the dense building concentration in Avenida Baia dos Golfinhos (North part of the ringy route), as well as the two shortcut routes, one linking the Northwest and Southeast ends of the village main street (that includes the Avenida), the other connecting the entrance road to Pipa and the settlement of Cabaceiras.

The configuration analysis suggests, however, that the access hierarchy, both as concerns Pipa’s inner space structure and that of Pipa in relation to the other settlements is maintained after the insertion of the ring. The strong linear centrality anchored in Avenida Baia dos Golfinhos is also sustained. On the other hand, the linear growth of the settlement southward is generating newly occupied thoroughfares, some of which already highly accessible, that seems to anticipate the formation of centralities more likely to relate to vehicular movement. Some recent constructions these new roads – such as large gated condominiums, petrol stations / garages and building material warehouses – reinforces this conjecture.

2. MEASURING CHANGE AND CONTINUITY IN SPACE AND USE

In the current investigation of properties, which have been associated to sociocultural animation we have considered the idea of networks of linked centres that favour the establishment of movement-driven activities, which, in turn, may anchor the formation of “active centres”, as

Figure 1 - ‘Spiky’ Pipa connecting another settlements of Tibau do Sul into a deformed grid that conform to its sloped natural site. New and widened roads which form a circular circuit (road ring) with Avenida Baia dos Golfinhos. Datasets: IDEMA (2006), Google Maps (satellite image, 2013).
suggested by Hillier (1999) and Vaughan, Jones, Griffiths & Haklay (2009). The variety of the activities as well as the relative position they occupy in the street grid are also considered in combination with the spatial hierarchy. Within a less “objective” approach, the investigated physical and functional datasets were checked against the empirical knowledge of the researchers (one of them former resident in Pipa, to this day a frequent visitor), photographic surveys of Pipa’s central spaces and complementary source from the literature and narratives.

The temporal dimension is given by comparing physical attributes before (2006) and after (2013) the road development of 2008-10, which motivated the hypotheses about a possible “rupture” concerning the qualities of urbanity that have turned Pipa into a national and international holiday destination, a sought-for place for a second or even permanent residence. It is obvious, though, that these temporal milestones serve mainly our epistemological purposes since space transformation is a continuous process and centrality the “outcome of a long-term historical process of the formation and location of centres” (Hillier, 1999, p.107). The idea of “rupture” would, in our view, be sustained by a substantial change in the hierarchy of accessibility, potential movement and land use, what did not take place.

Granted that the block size is a physical attribute thought to affect potential movement (Jacobs, 1961), attractiveness and the “mixture of uses along them”, as verified in numerous empiric studies (see compilation by Netto, 2016), these aspects were examined by calculating segment length and number of segments per kilometer, although the researchers understood that these parameters are not precise, since in Pipa, segment length does not correspond to block size due to the sinuous shape of various streets that generate segments which do not necessarily correspond to street intersections. Long blocks can, therefore, be formed by various small segments. Therefore, we chose to count activities both per segment, as proposed by Vaughan (2009, p7-8) and per block, presenting the average size of the measured segments and blocks.

The linear representation of Tibau do Sul was drawn with QGIS (QGIS Development Team, 2016) over tiles from Google Earth 2013 satellite images. After that, the linear representation was fitted to an aerial photograph (Tibau do Sul, 2006) due to its higher precision to detail pedestrian ways as compared to Google Earth. Some lines were erased from the 2013 map to model Tibau do Sul before the road ring construction.

The narrow pedestrian pathways were updated in another layer based on a GPS survey made with a GPS-logging application (OSMTracker, 2017), including the sand stretches walkable at low to medium tide. This layer was joined to the main layer to gauge the possible effect of footpaths on local measures.

The linear representation of footpaths was constructed for Pipa only. The 2006 representation was drawn from the memories of Martins, author of this paper, who lived in Pipa from 2004 through 2009. Some existing beach paths were not represented as they are limited by tides other than very low ones as well as by the formation of salt ponds – the maceios – after high tides in certain months.

The representation was checked and analysed with Space Syntax Toolkit (Gil, J., Varoudis, T., Karimi, K., & Penn, A., 2015). Axial integration (IntHH) and axial choice (CH) were analysed with radii \( r=3 \), n. Normalized Segment Angular Integration (NAIN) and Normalized Segment Angular Choice were explored with 17 radii from 200m to 12000m.

The land use records and the built area representation for the municipality of Tibau do Sul in 2006, was obtained from an official document (Tibau do Sul, 2008), a raster image granted by Instituto de Defesa do Meio Ambiente (IDEMA, 2006). Land use categories were labelled as: “residential”, “commercial”, “institutional and services”, “hotels and hostels”, “condominiums”, “vacationers”, according to which use predominated in each polygon that corresponded to the built area projection. Each polygon may represent more than one building or premises as, for instance, a dwelling or dwellings and hostels in different floors or galleries with diverse retail or service outlets.

As concerns land use categories, “commercial” refers to retail in general, including restaurants, pubs and private services such as travel agencies, currency exchange etc; “Institutional and
services” refer to public or to what is expected to be predominantly non-lucrative service, such as health centres, police stations, schools. "Residencial" refers to dwellings in general; however, two other labels were added to specify habitation schemes that are numerous in the studied case and relate to different communities, thus bearing important sociocultural implications. "Vacationers" are dwellings occasionally inhabited by people who reside elsewhere for most of the time and keep a second (third or whatever) residence, usually for leisure purposes; "condominiums", referring to multiple dwelling units sharing the same land plot may also serve as second residences, but are often unofficially used as hostels or boarding houses.

There is no land use official record for 2013. This problem was partially overcome by constructing one, based on local surveys and photographic images gathered in September 2016. In contrast to the analysis of space configuration, the land use comparison across time relies more on a qualitative evaluation than on a quantitative examination, since the 2006 record displays little information about non-residential uses and what is being served as a proxy to a 2013 record is a loco survey carried out three years on, which although much more detailed, focus on Pipa’s central areas and their surroundings plus some selected spots. However, we trust that despite these limitations, the examined data and analysis procedures are robust enough to anchor findings, thus contributing a case study to the knowledge about centrality formation or 'centrality as a process' (Hillier, 1999).

3. AND THE SPACE HIERARCHY CARRIES THE PROCESS ON...?

There is no substantial difference concerning the topological measures before and after the construction of the road ring in terms of integration and choice (segment [NACH/NAIN] r=n and 200 to 12000m and axial [intHH/choice] r=n_3), except for some footpaths. Figure 2 compares the spatial configuration before (2006) and after (2013) the road works, showing that the hierarchy of topological accessibility remains the same, regardless of the representation procedure or measure explored. These were integration [INT] for axial analysis and normalised integration [NAIN] for angular segment analysis, choice [CH] for axial analysis and normalised choice [NACH] for angular segment analysis, both for the global and local scales (r = 3, [R3]). Similar findings resulted from the calibration of the segment maps for 17 different metric radii, ranging from 200m to 12000m, based on the two maps (2006 + 2013), that added up to 37 representations.

Most of the accessibility core for the global scale comprising the spatial configuration that includes Tibau do Sul, Pipa, Cabceiras, Piau and Sibauma is formed by Pipa’s urban network. Only locally [R3] is the street grid of Tibau do Sul more integrated. High through-accessibility [CH] is found, not surprisingly, on the roads connecting Pipa to Tibau do Sul and to Piau. The new road link Pipa-Cabeceiras will share (and dilute) accessibility with those roads.

The 2013 map of Pipa’s street grid was reworked to include the representation of pedestrian only routes – alleyways, open air stairways (connecting lower and upper towns), and the walkable stretches along the waterfront in low tide. No substantial change in the hierarchy of accessibility, locally and globally, was noted when the representations before and after the road works were compared. Figure 2 shows that part of Avenida Baia dos Golfinhos’s northern and southern sides are highly accessible and that the accessibility core shows a tendency of expansion towards south even before the road ring. The axial global integration [INT] for 2013 highlights the circular contour of the road ring, outlined from highly integrated lines since at least 2006. At the southern end of the integration core the Avenida splits into two ways, forming an inverted Y-shaped whose accessibility values are on the upper side of the scale before and after the road ring in all measures [INT, CH, NAIN, NACH].
The addition of footpaths shows a tendency for the formation of highly to-accessible [INT] circular routes in 2006 that fades slightly in 2013 (from red to orange) and falls some points in the hierarchy scale as compared to the new road stretches. Through-accessibility [CH] is however strengthened, as some red segments stretch towards the inverted Y-shaped compound, what does not come as a surprise considering that the measure picks up the grid skeleton. With footpaths considered for local integration [INT \( r=3 \)] the axis running along and offering access to various second homes or season houses (labelled here as "vacationer" houses rather than "residential"), below Avenida Baía dos Golfinhos is even more accessible than the Avenida's average. This highly accessible path highlights the importance of the central beach – the only beach included in the perimeter of Pipa due to the discontinuity of the cliff line, a key site for the original fishing trade, now the heart of Pipa in daylight.
Figure 3 - Segment length, projection of buildings and land use. Dataset: aerial photograph (IDEMA, 2006), Plano Diretor (Tibau do Sul, 2008).

<table>
<thead>
<tr>
<th>Street grid and block attributes</th>
<th>Avenida Baía dos Golfinhos</th>
<th>New and widened street</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segment length, mean</td>
<td>64.6</td>
<td>104.7</td>
</tr>
<tr>
<td>Block size, mean</td>
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<td>157.4</td>
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<tr>
<td>Segments per kilometre</td>
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<td>9.8</td>
</tr>
<tr>
<td>Length (m)</td>
<td>1938.3</td>
<td>2014.6</td>
</tr>
</tbody>
</table>

Land use (2016, photograph survey)

Avenida Baía dos Golfinhos: Restaurants / bars, hotels / hostels, chemistries, residential condominiums, one-family dwellings, summer homes (‘vacationers’), groceries, bakery, beauty parlours / hairdressers, automated teller machines (ATM) / bureaux de change, worship places, car rental, nightclubs, parking, bus terminal, space for concerts and outdoor events, school, health centre, square, car service (tyre repair).

New and widened street: Hotels / hostels, residential condominiums, one-family dwellings, school, warehouses (buildings material and timber), beauty parlours / hairdressers, worship places, groceries.

Table 1 - Segmentation and land use
4. CONCLUSIONS

Pipa has the largest street structure amongst all settlements in the municipality, including that of its seat - Tibau do Sul. Half of all segment lines (487 segments of 977 total segments in 2013, 429 segments of 911 total segments in 2006) are there (Figure 3). High global to-accessibility coincides exemplarily with variety in land use, whereas high through-accessibility tends to reinforce uses related to local centralities, although this is hardly a rule as some of them – especially longer segments – are not sided by non-residential uses, a finding that makes us recall Jacob’s (1961) defense of small blocks as generators of street animation.

Avenida Baia dos Golfinhos, Pipa’s main street, connects other settlements along the road to the neighbour town of Goianinha. The links spreading out of the Avenida, formed by the segments with the densest occupation, recalls Hillier’s (1999) spiky potato, each spike becoming a potential generator of other centres as they connect to the segments belonging to those destinations, which, in turn, help to increase the movement potential, mostly northwest and west of Pipa. As the village cannot expand towards north and east – limited by the sea line – the Southern spikes conduct the road network expansion.

Figure 4 - Local through-accessibility [NACH, r=600m] and diversity of activities and users in the new and widened roads. Dataset: Google Maps (tiles of satellite, 2013); SST-QGIS; photography survey (2016-2017)
The road from Pipa to Sibaúma is mostly an earth track mainly trod by vehicles related to tourism. The recent road ring increased the paved stretch up to a third of its total length, adding a shortcut that allows vehicles to avoid Avenida Baia dos Golfinhos and, therefore, Pipa’s live centre on the way back from Sibaúma to all other settlements within the municipality, to Goianinha and to the BR101, the main federal road connecting the capital cities of the Northeast region. The former two-way movement along the Avenida is now reduced by half. Although this could theoretically reduce animation in the area, it should be taken into consideration that accessibility properties are not sensibly affected by the new roadworks and that return routes across a busy and densely occupied area may contribute more to bring congestion than to boost animation. This idea is strengthened by the fact that, on occasion, the busiest street segments in the Avenida were closed to motor vehicles after seven in the evening and residents and shop owners often argued in defense of the creation of a pedestrian-only stretch in the Avenida, now also freed of heavy service traffic, and cargo vehicles such as the frequent lorries loaded with building material that feed the expansion of resorts and holiday homes south of Pipa.

The sand stretch belonging to Pipa’s central beach is even more highly accessible (in the local scale – INT $r=3$) than Avenida Baia dos Golfinhos. This is the only beach within the village borders in which a break in the cliff chain allows for pedestrian (and vehicle) access along the shore and between Pipa’s lower and upper settlement. It is a diversified busy spot that has always been very important to sustain the village economy, especially related to fishing. Fishermen dwellings once occupying the beach were gradually substituted by summer houses and uses related to leisure and tourism. This diversity is not fully picked out in the land use map since various facilities are not represented as a polygon. Playing and recreational equipment, a garage for fishing and leisure boats, huts in which an ample variety of goods, especially food and drink, are sold and the numerous table-plus-umbrella spread, besides the appealing rock
topped by the statue of Saint Sebastian (Pipa’s patron saint) are such examples. These share
space with restaurants, hostels, a chapel that lost its former view of the sea, screened from it
by the many summer homes.

Figure 6 - Local through-accessibility [NACH, r=600m] and diversity of
activities and users in the Avenida Baia dos Golfinhos and the widened
streets. Dataset: Google Maps (tiles of satellite, 2013); SST-QGIS;

The highest accessible line in the grid runs along summer residences, this being a good
reason to distinguish “vacationer” (or “non-residential”) from “residential” in the 2006 plan,
thus emphasizing the contours of an active space in the light of Vaughan et al. (2009). Intense
pedestrian movement coincides with high local accessibility there. As has been mentioned
earlier, the occupation by holidaymakers dates, at least, from the early 20th century, when the
dam that separated the Lagoa de Guaraíras from the sea burst and flooded Tibau do Sul’s urban
settlement so that sugar mill farmers from Goianinha that used to spend their summers there,
opened tracks in the woods between Piauí and Pipa, and initiated the beach as a vacationers
destiny. The accessibility measures relating to pedestrian footpaths along the beach appear to
capture the memory of this occupation.

The diachronic segment representation shows that the road ring reduces some of this high
local accessibility. However, this should be taken cautiously as it was impossible to ascertain the
moment in time (from 2006 to 2013) when segments were broken due to the enclosure of farms
and plots. Part of the difficulty to represent footpaths diachronically has to do with the fact
that many such paths cut through private property formerly not enclosed. Occupation was then
more permeable to pedestrians and may have been reduced by walls and fences that affected the richness of potential encounter. This could have interfered with the configuration analysis before and after the road ring.

On the other hand, the increase in accessibility in the ways running south of the village reinforces a tendency already outlined in the 2006 spatial configuration. The inverted "Y-shaped roads that fork southeast and southwest from the Avenida, which is already part of the integration core in the 2006 representation, with or without footpaths, is strengthened after the road works signaling what seems to be the route towards the formation of new linear centralities.

However, although reinforcing a configuration tendency which has been outlined a decade ago, this probable linear centrality on the make is unlike to replicate the kind of linear centrality that has helped make Pipa a lively, mixed, diverse, 24-hour magnet as it lacks the ingredients small blocks and many corners as observed by Jacobs (1961), about the conditions for city diversity, and Hillier (1999) about the process of centrality formation. Even if the sinuosity of some streets renders segment length unreliable to measure block size, the contrast within the central area is striking. The average segment length north of the Avenida is much shorter than that south of it (64.6m against 104.7m), as is the distance between blocks, considering the number of segments per kilometre (15.5 against 9.8 segments per kilometre).

The land use representation shows that routes with greater activity and variety of uses are associated to shorter segments and shorter distance between blocks as displayed in table 1 and figure 3. Animation, therefore, tends to concentrate there. A sensible difference between the north and the south ends concerning the presence of people on the street is noted as one walks along Avenida dos Golfinhos and its intersecting ways, which is illustrated by the photograph survey presented in figures 4, 5 and 6. Whereas the street images support the idea that the physical attributes in the southern end constitutes a scenario less conducive to pedestrian movement and encounter, the list of non-residential land use found there reinforces the idea that we are witnessing the formation of a linear centrality that favours large developments and functions, whose movement nexus is that of the automobile.
REFERENCES


SPATIAL ACCESSIBILITY AND COMMERCIAL LAND USE PATTERNS
Planned Versus Unplanned Areas in Cairo

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ABSTRACT
This paper shows the research results from a research project investigating the relationship between spatial configuration and the distribution of commercial activities in throughout planned and informal urban environments. The research methodology uses space syntax analysis as well as statistical calculations. The spatial accessibility model is combined with commercial activity data from three different types of settlements in Cairo: The throughout planned Al-Sharekat, and the informal areas Ezbet Al-Nasr and Abu Qatada. As a contrast to Cairo’s informal areas, the throughout planned Al-Sharekat area is a typical example of modern urban areas with a planned modern urban shopping centre.

The results demonstrate that micro scale businesses, run and owned by low income people, are sensitive to having high degree of spatial accessibility to potential customers. This spatial feature is missing in the throughout planned Al-Sharekat. Accordingly, unplanned areas are not chaotic in terms of commercial activity patterns. Finally, superficial insights that distribute activities on the principle of abstract geometric distance, such as putting the service centre of the neighbourhood in its geographical centre should be revisited.

KEYWORDS
Commercial activities, economic gain, throughout planned areas, informal areas, Space syntax

1. INTRODUCTION
How are commercial activities distributed in throughout planned areas? How does their location pattern differ from the unplanned urban areas? Here we wanted to compare research results of a throughout planned urban area with research results from informal urban areas. Rapid urbanisation of Cairo metropolitan area has resulted in massive urban expansion the last 20 years. Throughout planned as well as unplanned settlements are built on the peripheries of the city on a privately-owned ex-agricultural land and on a state-owned desert land (GTZ, 2009). The high-income dwellers are facilitated with high quality dwellings inside throughout planned neighbourhoods and with provision of inward oriented shopping centres with luxury goods.

On the other hand, low-income groups seek for the spatial opportunities of the settlements to generate any kind of income for surviving. There is a social logic in both the geographical location of unplanned urban areas and the structure of the spaces between buildings inside these areas (Mohamed et al, 2015).
Many planners and high-level decision makers share misconceptions of informal areas as being unstructured and chaotic whereas the planned areas have a clear spatial structure (Shehayeb, 2009). This paper, using evidence-based approach, demonstrates that informal areas, unlike planned quarters, are not chaotic in terms of commercial activity patterns as shops are structured along the shortest possible paths to minimize travel cost. This is exactly what environmental design strategies, economists, and sustainability policies are calling for.

This research, using space syntax method as well as statistical analysis and the Gini coefficient of inequality, focuses on revealing the extent to which the dispersal of commercial activities is influenced by the spatial accessibility model. The key question is: what is the logic behind the way commercial activities are distributed within a polycentric metropolis such as Cairo?

The thorough planned Al-Sharekat neighbourhood in Nasr city (belonging to the Cairo metropolitan area) is used as a case for revealing the location pattern of various types of commercial activities as contrast to two informal areas: Ezbet Al-Nasr in Al-Basateen, and Abu Qatada in Boulaq El-Dakrour district. Importantly, the land on which Nasr city was built is a desert formerly attributed to the ministry of Defence. The establishment of the city was initiated in 1960s by President Gamal Abdel-Nasser who aimed at building a socialist country based on Arab nationalism and cultural and spiritual values (Herzog et al, 2009). Conversely, Ezbet Al-Nasr is established on a state-owned desert land close to the city centre, while Abu Qatada is built on private former agricultural land illegally built on the fringe of the city. Moreover, the two cases are all self-organized and relatively similar in terms of size and age.

2. PREVIOUS RESEARCH RESULTS

Current theories and approaches concerning location of economic activities within the urban environment lack integration between the various disciplines. In an earlier research focusing only on informal settlements, various contributions from geography, economy and urban morphology showed that patterns of economic functions cannot be understood only in terms of market mechanism as geographic distance is not the only variable for allocation and organization of economic activities. Consequently, a theory of space-economy still represents as a major gap to be tackled in different perspectives.

As space syntax research has shown, when commercial activities are concentrated along most accessible routes, they get the optimum benefit from the movement and this in turn facilitates urban consolidation. The percentage of commercial functions (shop, workshops and kiosks) on outward edge of a settlement influences the degree of urban consolidation. This percentage is called ‘Edge Oriented Commercial Activity’ or EOCA1 (Hillier et al, 2000; Shafiei, 2007).

Another study (Porta et al. 2009) examined the relationship between street centrality and intensity of retail and service activities in Bologna city using Kernel density tool to transform the original data of centrality and commercial and service activities to one scale unit to do regression analysis between them. The findings indicated that activities are most likely to concentrate in more central, easy accessible, locations.

However, it is not clear whether the outcomes of previous researches can be demonstrated in medium size settlements or whether they are peculiar to small size areas, where internal commercial streets are not expected to be found (Mohammed et al 2015). Moreover, It is not clear whether such findings can be extended to informal areas in other regional context such as Cairo.

In an earlier research project on informal settlements, we investigated the relationship between spatial variables and the pattern of internal and edge commercial land use by applying various tools, such as space syntax analysis, Inter-visibility between private and public space (van Nes & López, 2010), and statistical calculations. The cases used in this study were three informal areas in Cairo that are predominantly self-grown and have not been influenced by city plans or land use regulations.

1 The formula for calculating this ratio is as following: EOCA= 10(shops/plots) + 10(edge shops/ plots) + (edge shops/ shops) (Hillier et al, 2000)
Importantly, the results have demonstrated that commercial activity pattern follows the spatially most accessible, most distributed and most inter-visible parts of the settlements in relationship to the wider urban context. The findings enhance better understanding of a theory of an optimal distribution of plots, in which optimal land use is defined by two main variables: inter-visibility and street network accessibility. The next question is then, how does an optimal distribution of plots occur in a throughout planned urban area?

Remarkably, Lerman and Omer (2013) investigated the role of spatial and functional built environment attributes in shaping pedestrian movement in pre-modern and modern areas in the centre of the city of Tel-Aviv. The results indicate that in pre-modern environment, the spatial distribution of pedestrians has stronger correlation to spatial accessibility parameters than in modern in environment. Differently, the research presented here focus on understanding the effects of the spatial-configurational properties of street network in shaping commercial and service activities in planned and unplanned urban environments.

3. METHODOLOGY

The through planned Al-Sharekat in Nasr City is a home for 8900 inhabitants living over 41 hectares (UNDP, 2008), while Ezbet Al-Nasr is inhabited by 60,000 people living over 30 hectares (IUSD, 2013). In addition, Abu Qatada hosts 27,016 people occupying 28 hectares (CAPMAS, 2006). The space syntax method is used to study the relationship between the spatial structure of urban environment and economic activities.

This paper is structured in two parts. The first part analyses the spatial structure of the three cases at global and local scales. In the second part, statistical analysis and the Gini Coefficient are employed to investigate of the relationship between spatial attributes and the pattern of commercial uses.

3.1 SPACE SYNTAX

The axial map, progressively, was developed into a segment map where the street segment between junctions is the spatial element (Hillier and Stonor, 2010; van Nes, 2011). The structure of the urban grid, then, shows the potential movement of people since spaces with high syntactic values will generate co-presence and interaction higher than spaces, which are syntactically segregated.

There are two measures of potential movement: to-movement potential (closeness or syntactic integration), or the potential accessibility of a segment regarding to all others; and through-movement potential (betweenness or choice), or how likely a space will be crossed with respect to all other pairs of segments (Ibid.). The syntactic measures of each segment can be applied at different radii from each segment to show potential movement for different scales from local to global. More simply, spatial analysis at a global scale takes into consideration all street segments comprising the whole urban system, while analysis at a particular radius, confines calculations for each segment to the defined catchment area. For example, spatial accessibility at radius 1200 meters measures spatial proximity of a segment within only 1200 meters.

Importantly, the radius of analysis can be defined by three weights of distance: the metric distance which defines a street network by the shortest physical distance, the topological distance which calculates a street network in terms of the fewest number of direction changes, and finally the geometrical distance which measures a street network by the least angle change path (Hillier & Iida, 2005).

Normalising the angular choice measure was introduced by Tao Yang in Hillier et al. (2012). Normalisation enables comparing urban systems with different sizes with each other. Consequently, a neighbourhood could be compared with the whole city and with smaller urban systems as well. Actually, it is more important to normalise on the local scale than it is on the global scale (radius n), because radius n is a constant. Normalisation can be problematic in areas where there are huge variations between sparse and dense grid.
Space syntax method is used in this research to investigate the degree to which the case study areas are accessible at both local and global scales. On the other hand, statistical correlations are made to test the spatial model of the street network configuration as a background of distribution of economic activity.

3.2 STATISTICAL ANALYSIS

The number of dwellings on a street segment affects commercial activity rates that increase with more buildings on the segment. We have learned that using the band analysis, developed by Hillier and Sahbaz (2005), to compensate this logarithmic function might give misleading regression results with a fine-resolution dataset due to that grouping commercial activity data into bands according to the total number of plots on the segment will significantly smooth the sample thereby normally producing significant correlation results.

Accordingly, we did regression analysis between each commercial street segment and the number of shops on that segment. Complementary, a method independent of segment length and plot count on a segment, the Gini Coefficient, was conducted.

The Lorenz curve is used in various disciplines such as economics, ecology and in studies of biodiversity to see whether a particular aspect (e.g. income) is equally or randomly distributed. It correlates the accumulative proportion of a factor to that of another (Duclos and Araar, 2006). ‘Gini coefficient’ is obtained by dividing the area sandwiched between the line of maximum equality (a line of 45 degrees) and the Lorenz curve by the total area under the line of equality (see figure 1). Similarly, if the ratio of commercial uses, captured by a particular class interval of accessibility rank, is calculated and plotted on y axis against the percentage of accessibility on the x axis, then a Gini coefficient can be obtained and the degree of equality in shops distribution can be revealed.

![Figure 1 - Graphical representation of the Lorenz curve and Gini coefficient. Gini = A/(A+B) (source: van Koppen and Cullis, 2007).](image-url)
4. COMMUNITY’S GENERATING ACTIVITIES IN THE CASE STUDY AREAS

Informal areas in Cairo have emerged without any kind of planning. Mixed-use of functions is a frequent phenomenon in informal areas, where the ground floor is often used for micro-economic activities. Commercial activities exist over outer roads as well as internal streets and alleyways. In the two informal areas there are two types of community’s economic activities:

a) Local shops such as groceries, bakeries, restaurants, coffee shops, clothing, street vending and hairdressing salons. Such activities are usually located along alleyways to provide essential daily goods. Daily markets exist within informal areas, where street vendors share the street with shop owners and passers-by.

Like informal areas of Abu Qatada and Ezbet Al-Nasr, supermarkets and other kinds of local shops are situated in the ground floors of apartment blocks in Al-Sharekat neighbourhood in Nasr City.

b) Vocational activities such as car-repair, carpentry, iron-work, building material, junk trading, and marble processing are mainly located along external streets to facilitate service for outsiders, who are usually middle and upper class. Here, residents of informal areas try to generate any income through establishing their workshops along active edges of their settlements.

Unlike the two unplanned areas, light manufacturing activities such as workshops are missing in Al-Sharekat settlement. Rather there are global integrating activities that provide services to non-local as well as local residents such as hotels, cinemas, car Expo and banks. Notably, governmental buildings are commonly walled and located on the neighbourhood borders, while unaffordable activities such as car Expo are usually inward oriented.

Figure 2 - Locations of the case study areas within the context of Cairo Metropolitan
a) Land use in Al-Sharekat

b) Land use in Ezbet Al-Nasr
c) Land use in Abu Qatada

Figure 3 - Spatial location and land use patterns in case study areas
(source: Authors)
5. MORPHOLOGICAL ANALYSIS

In order to understand the influence of spatial configuration on movement and land use pattern, we need first to grasp the case study areas within the context of whole Cairo. Figure 4 shows the normalised angular global integration $R_n$ of the three cases. The black lines show the highest values, while the light grey streets are the lowest ones. Apparently, Al-Sharekat neighbourhood is the most integrated globally, while Ezbet Al-Nasr is the most segregated.

Figure 4 - Normalised angular global integration $R_n$ in Al-Sharekat (top left), Ezbet Al-Nasr (top right), and Abu Qatada (bottom).
At a local scale measure, morphological differences can be captured between the three case studies (figure 5). Syntactically speaking, Abu Qatada has the highest local potential movement/normalised angular integration R400 meters, while Al-Sharekat has the lowest value. This reveals that unplanned areas function properly at a settlement level, but has introvert behaviour within the wider context. Conversely, throughout planned areas function poorly on a local level, but is strongly connected to the wider metropolitan area.

Figure 5 - Normalised angular integration R400 in in Al-Sharekat (top left), Ezbet Al-Nasr (top right), and Abu Qatada (bottom).
The map of node count 400m reflects the degree of intensification of urban grid in the case study areas (figure 6). Unplanned areas have larger number of street segments (node counts) in short metric distance than planned ones. In Ezbet Al-Nasr, the urban grain structure is small in the central area and eastward where black lines are dominating, while western parts have larger sizes in light grey segments. The school complex, the cemetery, the vacant plots, and the sewage treatment plant are shown in the light grey spectrum. The large block size in such places might explain why pedestrian movement is low around. Slaughterhouse and cemetery blocks seem to segregate the neighbourhood from north and west respectively. Similarly, Abu Qatada has a small grain compared to surrounding parts (e.g. Cairo University campus) with coarse grain urban structure in the light grey range.

Figure 6 - Node count R400m in Al-Sharekat (top left), Ezbet Al-Nasr (top right), and Abu Qatada (bottom).
Table 2 summarizes the spatial parameters of the case study areas. It shows that Al-Sharekat is more globally and locally integrated than the three informal areas.

<table>
<thead>
<tr>
<th></th>
<th>Al-Sharekat</th>
<th>Ezbet Al-Nasr</th>
<th>Abu Qatada</th>
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<td>Mean normalised angular integration R400</td>
<td>0.619937</td>
<td>0.738241</td>
<td></td>
</tr>
<tr>
<td>Mean Node Count 400m</td>
<td>93.323615</td>
<td>515.689922</td>
<td>421.120629</td>
</tr>
</tbody>
</table>

Table 1 - Values of syntactic attributes for each case study.

Figures 7, 8 and 9 show the visualized angular choice for the three areas at radius 2000 meters, which is the best urban context radius of the neighbourhoods’ surrounding areas. A radius of 2000 meters highlights the main route network that is running through or between various neighbourhoods. An angular choice analyses show how good or bad a neighbourhood is connected to the local main route system, in which show the spatial potentials for a degree of contact possibilities between locals and random through travellers. The maps are coded thematically including ten equal quintiles with a spectrum that goes from dark black (for the 10% most accessible streets) to light grey (for most segregated ones). In the two informal areas, a visual interpretation of syntactic maps implies possible correlations between syntactic parameters and commercial uses distribution (shown on the maps as dots). It implies that shops and workshops are mainly located along the most accessible segments. Furthermore, residential buildings tend to cluster along the most segregated streets.

In contrast to the informal settlements, Al-Sharekat has the highest value on the local level as well. This planned area has much larger blocks and the local streets are more directly connected to the main routes than the informal areas. Unlike the informal areas, commercial activities in Al-Sharekat are distributed more randomly. The ratio of the plot with commercial activities located on the border to the total number of shops in Al-Sharekat is remarkably lower than the two informal areas. Furthermore, residential buildings tend to cluster along the most segregated streets. However, statistical analysis is needed to demonstrate the existence of such relations.
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Figure 7 - Al-Sharekat's normalised Angular Choice R2000m overlapped with the distribution of commercial activities.

Figure 8 - Ezbet Al-Nasr's Normalised Angular Choice R2000m overlapped with the distribution of commercial activities.

Figure 9 - Abu Qatada's normalised Angular Choice R2000m overlapped with the distribution of commercial activities.
6. THE CORRELATION BETWEEN COMMERCIAL RATE AND SPATIAL ATTRIBUTES

In order to quantify the configurative findings, regression analysis method is employed. Table 2 shows the relationship between commercial activity count per segment in the case study areas and segment length as well as the normalised angular choice (NACH), weighted by segment length (SLW), at different radii. There are significant positive correlations between patterns of commercial activity and segment length as well as normalised angular choice in the unplanned areas, but not in Al-Sharekat. Further, the analysis demonstrates that segment length and NACH R2000 (SLW) are the best predictors of commercial segments in informal areas. In other words, economic activities in unplanned areas are distributed efficiently along routes with the highest potential through-movement at local, medium and global scales to capture local residents and vehicular movement as well.

Conversely, commercial activity in Al-Sharekat is distributed randomly. A potential explanation is that the service centre of the neighbourhood, and so all modern urban areas, is planned on the basis of pure geometric distance so that many activities are buried in the geographic centre of the area. Nonetheless, another statistical method independent of segment length and number of plots per segment is needed to complement the previous findings.

<table>
<thead>
<tr>
<th></th>
<th>AI-Sharekat</th>
<th>Ebzat Al-Nasr</th>
<th>Abu Qata</th>
<th>[ \text{Segment Length} ] Pearson Correlation</th>
<th>[ \text{Segment Length} ] Sig. (2-tailed)</th>
<th>[ \text{Segment Length} ] N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>[ .557** ]</td>
<td>[ .373** ]</td>
<td>[ .227 ]</td>
<td>[ \text{Combined angular Integration and Choice} ] Pearson Correlation</td>
<td>[ .279** ]</td>
<td>[ .196** ]</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>[ .000 ]</td>
<td>[ .000 ]</td>
<td>[ 204 ]</td>
<td>[ N ]</td>
<td>[ 302 ]</td>
<td>[ 308 ]</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>[ \text{NACH}_Rn (SLW) ] Pearson Correlation</td>
<td>[ .273** ]</td>
<td>[ .182** ]</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>[ .000 ]</td>
<td>[ .001 ]</td>
<td>[ 981 ]</td>
<td>[ \text{NACH}_R2000(SLW) ] Pearson Correlation</td>
<td>[ .283** ]</td>
<td>[ .247** ]</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td></td>
<td></td>
<td>[ \text{NACH}_R800(SLW) ] Pearson Correlation</td>
<td>[ .282** ]</td>
<td>[ .238** ]</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>[ .000 ]</td>
<td>[ .000 ]</td>
<td>[ .642 ]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

Table 2 - The relationship between commercial activity count per segment and the local and global normalised angular choice weighted by segment length in the case study areas.

Complementary, looking at the percentage of commercial buildings captured by the top decile of accessibility can provide a numerical evidence for testing the hypothesis that commercial activities are unequally distributed and are placed along the most spatially accessible locations. Table 3 shows the percentage of commercial parcels in the top deciles of accessibility at medium scale radius (Choice R2000m). In the two spontaneous settlements, the results reveal that the commercial activities are structured along spatially accessible street segments to benefit from potential through movement. Similarly, the results of the calculated Gini coefficient values of the two informal areas indicate that the distribution of commercial activity is not random.
Unlike the two informal areas, the largest proportion of commercial activity in Al-Sharekat is captured by the top 30% most segregated buildings. On the other hand, the outward facing edges in Al-Sharekat have lower economic activities than the two informal areas of Ezbet Al-Nasr and Abu Qatada. Accordingly, economic activities in Al-Sharekat do not have the benefit of passing trade (see table 3 below).

<table>
<thead>
<tr>
<th></th>
<th>Al-Sharekat</th>
<th>Ezbet Al-Nasr</th>
<th>Abu Qatada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top 10% (Choice 2000m) Com.</td>
<td>8.6207</td>
<td>13.6824</td>
<td>15.1515</td>
</tr>
<tr>
<td>Top 20% (Choice 2000m) Com.</td>
<td>12.931</td>
<td>38.5135</td>
<td>37.1901</td>
</tr>
<tr>
<td>Top 30% (Choice 2000m) Com.</td>
<td>27.5862</td>
<td>56.0811</td>
<td>61.5702</td>
</tr>
<tr>
<td>Gini (Choice 2000m) Com.</td>
<td>0.18</td>
<td>0.39</td>
<td>0.39</td>
</tr>
<tr>
<td>Edge Oriented Commercial Activity (EOCA)</td>
<td>2.9790</td>
<td>3.2802</td>
<td>4.0151</td>
</tr>
</tbody>
</table>

Table 3 - Gini coefficient, EOCA, and Commercial activity distribution in the case study areas according to the upper percentages of accessibility (Choice R2000m).

As shown in figure 10a, the Lorenz curve of Al-Sharekat neighbourhood indicates that commercial activity is unevenly and randomly shared regardless of the percentile of spatial accessibility. Conversely, figures 10b and 10c show that commercial activity in both Ezbet Al-Nasr and Abu Qatada is influenced by the degree of spatial accessibility as the greatest proportion of shops tend to cluster along the most accessible buildings. Such findings are in line the Pearson correlations conclusions.

Figure 10 - The Lorenz curve of commercial activity distribution amongst all the plots in in Al-Sharekat (left), Ezbet Al-Nasr (middle), and Abu Qatada (left) based on the rank of spatial accessibility rank (NACH R2000m SLW).
7. DISCUSSION AND CONCLUSION

This study has presented the relationship between spatial configuration and the distribution of commercial activities of planned and unplanned settlements in Cairo. Notably, through planned areas lack opportunities for the establishment of micro scale businesses which often tend to lack a vibrant street life and large variation of all types of enterprises. Furthermore, economic activities taking place in the planned area of Al-Sharekat are located along internal routes with poor spatial accessibility. This minimises the economic gain as a result of time-consuming travels.

Conversely, in the spontaneous settlements, commercial activities are usually concentrated along higher-accessibly street segments and not just limited to outward facing edges. Apparently, residents of informal areas seem to have a local knowledge of their neighbourhoods, specifically a proper knowledge of spatial conditions that can get the chance of capturing passers-by. Expressed differently, possibilities of urban economics are very much dependent on spatial configurations of street networks.

There exist several studies on a natural location pattern of commercial activities in unplanned urban areas. These cases are useful for finding explanations on how of commercial activity takes place in urban space with a lack of regulations. In Hillier et al (2000) and Greene (2003) research on 17 small-sized (about 4.83 hectares) Chilean informal settlements, the axial analysis showed some correspondence between the concentration of commercial activities and the pattern of topological integration. Because of the small size selected cases, the results demonstrated that locally well-embedded settlements develop commercial activities on their busy borders, ‘an edge economy’, rather than within the internal routes. Studies on large informal neighbourhoods (about 172 hectares) in Zahedan city in Iran clarifies that there is a clear positive relation between the overall distribution of commercial uses and the degree of spatial accessibility at global scale (Shafiei, 2007). In an earlier research focusing only on informal settlements in Cairo, the use of the Gini Coefficient was a starting point for developing a theory of an optimal land use distribution, were the spatial accessibility is a key variable. We tried to reveal how the Gini Coefficient can be used to explain the distortion factors on the relationship between spatial accessibility and the location of commercial activities. As it turns out, often throughout planned areas lacks buildings with active frontages towards streets, the whole area tends to be inward or centrally orientated. To put it another way, commercial activity is generally buried in the internal urban structure of the selected planned area.

At present, we have focused on only one case study as regards the throughout planned areas. However, there exist examples on other similar cases throughout the world. The work of Ye and van Nes (2013) and van Nes and Lopez (2013) show that new towns in China and the Netherlands also have a lack of active frontages on a micro scale level, that there is a dis-correlation between local and global angular integration and hence affect the degree of variation of types of commercial activities.

What are then the first implications of a guidance that can be given to urban planners in such a rapid expanding city as Cairo? What we have learned so far is that a natural urban transformation process for aggregating micro scale commercial activities in informal settlements is at least depending on the following:

- Informal settlements strongly linked to motorways have better potentialities for generating retail opportunities than the poorly linked ones. The vehicular movement is a key element in connecting local residents to their workplaces and generating informal public destination economic businesses, which non-local residents can reach, along outward facing edges. In other words, such greater destinations are the threshold that links the formal parts with the informal ones.

- Locally accessible streets create micro-private destinations that meet the local population's daily needs.
• A mixed land use pattern fosters a wide range of economic premises. Sub-centres of informal areas, well connected to the wider urban context, transport investment from planned settlements and create economic opportunities for the metropolitan’s various quarters.

• Commercial activity should generally be planned on the basis of spatial accessibility that minimizes time consuming travels and maximizes economic gain and social interactions. Superficial insights that distribute activities on the principle of abstract geometric distance, such as putting the service centre of the neighbourhood in its geographical centre should be revisited.

Put in a nutshell, this approach itself can be used as a guide to the regeneration of unplanned areas and transferring investors and economic generating activities to deprived parts of the city. Many decision makers report unplanned areas as an explicit example of urban failure. Differently, another look at such settlements shows that they have some values and lessons to be learned. This research has approved that commercial uses in spontaneous settlements are orderly distributed along routes with the highest potential local and global movement patterns. This economic strategy is missing in a typical example of planned neighbourhoods in Cairo where movement-seeking activities are placed superficially at the geometric centre of the quarter with on attention to the urban structure of the quarter itself. Lastly, studying urban values in unplanned areas should be a source of inspiration for learning how to plan vibrant urban areas shaping opportunities for all kinds of people – whether they are shoppers or shop owners.

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Planned Versus Unplanned Areas in Cairo


#95

THE SPATIAL ORDERING OF KNOWLEDGE ECONOMIES:
The growth of furniture industry in nineteenth-century London

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ABSTRACT

Small businesses in the same sector tend to be geographically concentrated. Understanding why businesses in some industries cluster is a key issue in urban economic theory, particularly in the Marshallian and Jacobsian traditions. These emphasize the logistical and informational synergies (advantages) that accrue to firms in agglomeration economies, allowing firms located near one another to accelerate their rate of innovation. However, little is known about how spatial forms foster the clustering of firms or the mechanisms through which this process might facilitate knowledge spillover over between different businesses.

In this paper we present an historical case study in which space syntax methods, archival research and urban economic theory were used to enhance understanding of the spatial ordering of London’s nineteenth- and early twentieth-century furniture industry, a sector characterised by a proliferation of small, local firms. The spatial morphologies of the furniture industry in the Shoreditch and Fitzrovia areas of London are profiled by linking business directories, historical Ordnance Survey maps and Goad fire insurance plans to space syntax measures describing the spatial configuration of London’s street network, on a GIS platform. Historically, the two case-study areas have hosted a wide range of furniture-manufacturing businesses. We hypothesise that the contrast between the spatial structures of the two districts contributed to the divergent paths development of the furniture industry in these places.

Our results suggest the two areas developed as different knowledge economies, in part as a consequence of their contrasting spatial configurations and their influence on industrial organization. Shoreditch became a ‘specialization’ economy (i.e. Marshallian). Here the
organic pattern of streets allowed specialized businesses to be located in close proximity to key streets, benefiting from more local footfall, and in close localization of firms belonging to the same industry. Fitzrovia, however, showed a more ‘diversified’ economy (i.e. Jacobsian), accommodating most of its retailers on streets highly integrated across scales and more commercially-driven. In the context of constraints of land use and rising land values, manufacturing operations moved to other places whilst retaining large-size firms that created a retail destination in a high footfall location good for attracting passing trade. We anticipate that this research will contribute to understanding the distinctive spatial cultures of urban manufacturing and to the development of a methodological approach that opens up new prospects for inter-disciplinary research.

KEYWORDS
London, urban morphology, furniture, agglomeration economies, knowledge spillover

1. INTRODUCTION
The research presented in this paper stems from the idea that the spatial structure of nineteenth-century London’s furniture industry was able to accommodate the industry over time in ways that are resilient and sustainable. To the extent that the furniture industry as a whole is a complex system itself, we focus on the two following questions: What was the relationship between London’s street network and the spatial distribution of firms? And what was the nature of business connections between firms, if such connections existed? This study investigates these two questions in the districts of Shoreditch in the East End and Fitzrovia in the West End of London. By using Goad’s plans with historic business directories, in combination with space syntax methodology and GIS-based locational analysis, the paper presents descriptive and analytical maps examining the distribution of the furniture industry as it emerged in these two different areas in London (Griffiths and Vaughan 2016). This work aims to uncover the spatial relationships that may exist between firms’ location decisions and the innovator’s need to create or sustain a knowledge-based economy. In this particular case, we stress the role of dynamic externalities, or more specifically knowledge spillovers, for London’s furniture-industry growth. This paper addresses this issue by developing on the idea of knowledge-based economies and how they are spatially manifested in the two districts of London.

The study begins by expanding on the concept of knowledge per se in the context of economics and its relation to Hillier’s ‘generic form’ of the city (2016). The research expands on the concept of knowledge-based economies and its possible different spatial manifestations as those proposed by Marshall ([1890] 1920) and Jacobs (1969) and their respective hypotheses of knowledge spillovers as key for agglomeration of industries. Marshall’s view asserts that cities with production ‘specialized’ towards a particular industry tend to be more innovative in that specific industry, whereas the Jacobsian proposition argues that a ‘diversified’ production favours regional innovativeness. We hypothesize that both of these types of knowledge-based economies (specialized and diversified) were possible to establish in our two case studies due to their morphological and configurational differences in the city.

2. KNOWLEDGE, ECONOMIES AND URBAN FORMS AS SPATIAL KNOWLEDGE NETWORKS
Knowledge, by itself, is an understanding of structured and organized information that is acquired by learning, experience or through skills; or perhaps by sharing information and discovering new ones. In this sense, knowledge is not easy to measure, to interpret or to codify mostly due to its indivisibility – it requires a direct, face-to-face exchange of information between two players. Loosely speaking, knowledge can be understood as a form of interaction or transfer of information from one person to another in which both parties need to calibrate their explanation and interpretation of what is being communicated with each other. Therefore, a face-to-face interaction may well be a facilitating condition for knowledge transfer. Von
Hippel (1995) for example, has argued that knowledge is generally non-competitive, and the knowledge developed and shared can easily spill over and find other means to apply that knowledge in different ways.

This notion of shared knowledge between individuals has a resonance in the term known as **knowledge economies (or knowledge-based economies)**, which refers to the full recognition that the production, distribution and use of knowledge and technology are central to a city's economic development and growth. Since early economic theories, the idea that knowledge plays an important role in the economy is not new. Adam Smith suggested that in every economy there are new layers of what he called 'specialists who are men of speculation' (see Buckley 2014) and who make important contributions to the production of economically useful knowledge. Friedrich List argued that the infrastructure and the institutions which contribute to the development of production is achieved largely through the creation and distribution of knowledge (see Freeman 1995).

Since we are talking about knowledge, it is useful to distinguish what types of knowledge are produced in the advancement of societies and economies. Essentially this requires thinking about what, why, how and who creates, delivers and diffuses knowledge. In economic theory, these four aspects are described as the ‘know-what’, ‘know-why’, ‘know-how’ and ‘know-who’, respectively (see Figure 1; Lundvall and Johnson 1994). The know-what is the kind of knowledge that talks about facts, in what we commonly refer as information itself. The know-why is the kind of knowledge that underlies technological development and process advances in most industries; it is a production of knowledge that becomes more specialized.

The know-how refers to the skills or the capability to do something; it is typically the kind of knowledge developed within a business and that shares or combines other know-hows with other industries. And lastly, the know-who is what is perhaps the most important of all kinds of knowledge. It involves the information of who knows what and who knows how to do what. In this way, it involves the formation of social relationships which make possible access to other people’s expertise and use their knowledge efficiently. Whilst the first two kinds of knowledge, know-what and know-why, are usually obtained by learning from different sources of information and descriptions (i.e. books), the second two kinds of knowledge, know-how and know-who -also known as ‘tacit knowledge’ (Lundvall and Johnson 1994)-, are primarily rooted in practical experience.

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**Figure 1 - Diagram re-drawn based on Lundvall and Johnson’s descriptions of knowledge (1994).**

**THE SPATIAL ORDERING OF KNOWLEDGE ECONOMIES:**
The growth of furniture industry in nineteenth-century London
With knowledge and its diffusion comes innovation (or the process of discovery). The concept of innovation is largely associated with Schumpeter’s work on understanding innovation as a historical process for economic development. According to Schumpeter (1939, pp. 5-8), “carrying out innovations is the only function which is fundamental in history”. Development, then, is a historical process of structural changes that is substantially driven by innovation, and with innovation comes entrepreneurship (ibid). The ideas for innovation can stem from many sources, such as new manufacturing capabilities in light of market needs (Abramowitz 1989); and can assume many forms, such as improving existing products or using new tools and technology in new markets (Mansfield 1991). However, innovation is not a linear process. It requires communication amongst different actors and firms, as well as feedback between a process of manufacturing, the development of a product, its engineering and marketing (Fujita and Thisse 2001). Whilst in a knowledge-based economy innovation is driven by the interaction of producers and users, it also enables a distribution of knowledge through formal or informal networks –networks of relationships that connect them. We argue that within these networks of relationships that enable the diffusion of knowledge amongst agents and firms, proximity matters in connection to knowledge, and that the way linked spaces in the city are historically formed may play a role in how knowledge networks emerge and therefore contributed to the creation of knowledge economies.

The creation and diffusion of knowledge, which precedes the process of innovation, has been studied through the concept of ‘agglomeration’ – a term used by economists to refer to the phenomenon of firms being located close to one another. Economies of agglomeration theory (Glaeser 2010; Fujita and Thisse 2002; Marshall [1890] 1920) studies how economic life is concentrated in urban settlements where a variety of combinations of firms are clustered together. The theory argues that agglomeration results from the benefits of co-location, or being in close spatial proximity, of businesses in a similar field which can lower costs of transactions and production which in turn results in having more specialized businesses and division of labour (Dumais et al. 2002).

But what does knowledge have to do with urban morphology, or the generation of urban forms, in terms of agglomeration economies? In space syntax research, there is an increasing body of work addressing the need to re-think agglomeration economies as ‘spatial cultures’ of innovation (Griffiths 2017 forthcoming). From the perspective of industrial agglomeration and manufacturing innovation, a spatial and temporal description of agglomeration economies involves linking formal descriptions of urban structure (ibid: 4) within its social and historical context (Griffiths and von Lünen 2016). The link between diffusion of knowledge (information exchange) and spatial morphological agglomerations (urban activity) as spatial cultures is closely related to Lefebvre’s concept of “spatial practices” (1991:117) in which the history of space can help explain the development of networks and their inscription in space by means of human actions, especially work related actions.

Hillier (2016) has brought to the fore the relationship between the generic form of cities and how this may generate different kinds of knowledge acting as social networks. He suggested that the basis of understanding a city’s evolution and discerning what makes a city what a city is, lies in understanding the very nature of a city’s street network and its ‘dual process’ -a spatial and functional process-, which is suggested to be akin to a ‘genetic’ code of cities, namely the “generic form of cities” (Hillier 2009, 2014). According to Hillier (2016), through the spatial geometry and scaling of the street network, a city acquires a dual function, made up essentially by a dominant ‘foreground network’ that links centres at all scales due to its route continuity and where a high concentration of microeconomic activities may be expected (ibid, p. 200); and a ‘background network’ of more localized concentrations of socio-cultural activities by less linear continuity of routes, often associated with the production of residential space (ibid).

In line with the idea of the dual process of spatial urban structures, Hillier (2016, p.206) proposes to reflect on cities “as knowledge systems” in which social networks are produced by the generic city. As the “informational morphogenesis” of the built environment evolves

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that is, the function of cities to adapt as economies, information flows, human contact and technologies advance- two kinds of knowledge in societies arise: “practical knowledge” and “social knowledge” (ibid). The first relates to the microeconomic life of cities. Knowledge is constructed through non-local social networks as a collective information of individuals where the “interaction of knowledge groups [is expressed] in the foreground network”. Whilst the latter relates to the local networks of social relations that seek to create the ‘socio-cultural stability’ of cities where knowledge is built through the “interaction of spatially located groups [manifested] in the background network”. (ibid, pp. 208-211).

In the two propositions of knowledge by Hillier, we find similarities to those described by Lundvall and Johnson (1994) in terms of innovation. Practical knowledge reflects how a city works economically to develop and innovate, and therefore, the ‘know-what’ (facts) and the ‘know-why’ (understanding and development) can take place as a sparser social network. Social knowledge seeks to create ‘stability’ through the ‘know-how’ (skills that are shared or combined with other similar skills) and ‘know-who’ (social relationships) that make the denser and local social networks (Figure 2). Our proposition is to look at knowledge economies within these theoretical views as spatial knowledge networks -a network that is morphologically expressed as cities historically change over time (as practical and social knowledge develops), defining a spatial ordering of activities; and it is a network that reflects human capital (what, why, how and who creates the information necessary to construct the economic and social qualities for innovation). The core idea of knowledge-based economies is that all of our knowledge builds on things that we learn from others. But the central premise is that the presence of different types of knowledge enables spillover effects that produces agglomerations to take place (Paci and Usai 1999) and follows, we suggest, a certain logic of spatial ordering of activities in the urban fabric.

![Figure 2 - Associating Lundvall and Johnson (1994) and Hillier (2016) on descriptions of knowledge.](image-url)
3. KNOWLEDGE SPILLOVER: SPECIALISATION OR DIVERSIFICATION?

"...one learns that a cleaner of suede clothing is now starting to bottle and sell her cleaning fluid for people who want to clean their own suede; a chest and wardrobe manufacturer is starting, for a fee, to analyse what is wrong with one's household or office storage arrangements; a playground designer is starting to make and sell equipment for playgrounds and nursery schools; a sculptor is starting a line of costume jewelry; a designer of theatre costumes is launching himself as a couturier; a couturier is starting a boutique; an importer of Italian marble is starting to manufacture marble-topped tables; a clothing store is starting classes in teenage grooming and dieting” (Jane Jacobs 1969, pp. 53-54).

Agglomeration economies theories, such as Marshall ([1890] 1920) and Jane Jacobs (1969), have emphasized the role that cities can play in speeding the flow of ideas. Knowledge spillovers relate to the dissemination of tacit knowledge (know-how and know-who) as it can only be acquired through the process of social interaction (Henderson 1997). As such, knowledge spillovers can be limited to its spatial geography (Feldman 1994). There are several hypotheses on the nature of spillovers (or externalities) from an economic perspective, mainly by the contributions of Marshall (1920), Arrow (1962), Romer (1986) and Feldman and Audretsch (1999). Our interest here is to concentrate on two particular theories that seemingly appear opposing, yet we argue that both are equally valid depending on the spatial ordering in which externalities take place. Marshall (1920) emphasizes that knowledge spillovers occur as a form of ‘specialization’ (In: Glaeser et al., 1992), arguing that knowledge tends to be industry-specific, that is, industries specialize geographically because proximity favours knowledge exchange between firms within the same industry field and can only be supported by other similar (or complementary) firms. This is what economists term as Marshall's ‘localization externalities’ (Kelly and Hageman 1999), namely producing a specialization economy.

The alternative hypothesis is that externalities benefits the creation of new ideas across industry sectors as originally proposed by Jane Jacobs in her work The Economy of Cities (1969). Jacobs' hypothesis is that the variety of local activities plays a fundamental role in innovation given that it enhances the economy's capacity of adding more work, and as such, more goods and services. She argued that new skills and knowledge can create new businesses, or finding new uses for one's skills contributes to a local diversity. The knowledge of individuals develops a chain reaction of how one kind of work can lead to another: “The new work is added to older work first, and then sometimes its new divisions of labor are added to other appropriate varieties of older work” (ibid: 52). In this sense, 'Jacobs' spillovers' (Mehaffy 2001) asserts that the exchange of complementary knowledge across firms facilitates new forms of innovation. Having a diversified production of knowledge available for an individual firm would give rise to ‘urbanisation externalities’ (In: Glaeser et al., 1992), namely creating a diversified economy.

From an urban morphological point of view, we suggest that knowledge spillovers are also linked to a building's form and use as well as the influence of its urban location. According to Sternberg (2007), while a designer may be concerned with identifiable spillover effects of a building, the individual's greater concern is on the broader relationships of the building with other factors. This suggests that knowledge spillovers may also imply a spatial spillover effect, such as the relationship of a building to the connectivity of the street and its urban surroundings, views, the character of the neighbourhood, or other indirect factors like land values.

4. LONDON’S NINETEENTH-CENTURY KNOWLEDGE ECONOMY IN THE FURNITURE INDUSTRY: SHOREDITCH AND FITZROVIA

During the nineteenth and twentieth centuries, the London districts of Shoreditch and Fitzrovia contained hundreds of furniture workshops and factories. Cabinet makers, chair makers, table makers, polishers, upholsterers, sawmills, carvers and related businesses together produced a large portion of furniture sold in England and Wales. Located on a variety of kinds of streets, in commercially-transformed variations of terraced houses and small factory buildings, as well as purpose-built factories, showrooms and warehouses, they formed a coordinated system of production that initially operated “from the bottom up” rather than out of large, multi-functional factories.
Until the middle of the twentieth century, making a piece of furniture involved numerous craftspeople and suppliers of materials and tools that were distributed in separate business firms. These included production of the wooden frame, the crafting of parts such as turned legs for chairs and tables, the carving of ornament, upholstery—which itself entailed making and fitting a web for the fabric pile or stuffing, the possible insertion of metal springs, the stretching of fabric, and the securing of the fabric with pins or tacks; polishing; gilding; the installation of hardware such as hinges, drawer pulls, latches and locks. Suppliers provided timber and veneers, fabric and pile for upholstery, feathers for mattresses, polish, lacquer and varnish, upholstery trimmings, brass hardware, springs for chairs and beds, glue; upholstery tacks; and other products. Tools included hand tools and, increasingly, machines.

The various crafts were separate from each other, and suppliers might have specialized in only one product and a small range of related products. Because consumers wanted unique products, and crafts such as carving did not lend themselves to automation and remained the province of craftsmen and hand workers the furniture industry resisted standardization and mass production. Up until the absorption of individual processes into large factories in the beginning decades of the twentieth century, the furniture industry was made up of hundreds of small shops, each employing just a few workers at most. The shops worked in coordination with each other, in what may be regarded as a giant factory that was the city itself, in which products moved from shop to shop for different phases of production. The shops were all over London, but there were concentrations in two areas—Fitzrovia, near Tottenham Court Road in the West End, and Shoreditch in the East End (Figure 3).

The industry in Fitzrovia, particularly around Tottenham Court Road emerged first, as craftsmen such as Thomas Chippendale moved north out of the city and from streets like St Martins Lane. This part of the industry made furniture at the upper end and served wealthier clients in Westminster, Mayfair and similar neighbourhoods (Edwards 2011). In Fitzrovia there were many independent shops carrying out different operations of manufacture, but instead of the wholesalers, large retailers began to emerge as central firms. Retailers such as Heals and Maples brought the smaller firms into their own operations, in addition to dealing with subcontractors in the East End, and were thereby the centre of a ‘tree-like’ hierarchical industrial organization (ibid, pp. 3-5).

The industry in Shoreditch and the East End grew as demand for furniture from the middle and lower classes grew (Smith and Rogers 2006, p.8). However, the industry developed differently in the two places. In Shoreditch, the cabinet makers and wholesalers remained independent and subcontracted with a variety of other firms, including firms lower down the value chain like suppliers and firms such as wood turners, and firms higher up, like upholsterers and polishers. The wholesalers were central to the coordination of the trades, and sold to retailers all over London who came to their showrooms to buy goods (ibid, pp.16-17). While some of the wholesalers incorporated finishing trades within their own operations, a lot of their work was with other independent firms, and this organization persisted well into the twentieth century.
Figure 3 - Fitzrovia and Shoreditch at present: (top) wider urban context where both areas are located in London connected in the street network; (middle) aerial view of the urban fabric; (below) figure ground morphologies.
In Fitzrovia, then, when the industry grew it became fixed within the orbit of a few large retailers who had their stores on Tottenham Court Road, whereas in Shoreditch there was more fluidity as the wholesalers dealt with a variety of smaller craftsmen and suppliers. In his book The Industries of London (1961), Peter Hall claimed that the furniture industry in the East End was more resilient than that around Tottenham Court Road (ibid, pp.91-93). Indeed, the industry in the East End lasted until well into the twentieth century, while furniture manufacturing around Tottenham Court Road rapidly declined as the century progressed. By the middle of the century Tottenham Court Road had major furniture retail stores like Heals, and Shoreditch continued to house stores, warehouses, factories and the premises of various suppliers.

Although both places eventually gave up furniture manufacturing to large factories outside the centre of London that required more land than either central location could provide, Peter Hall’s statement remains a tantalizing one. If we assume it is true, based on the greater longevity of the industry in the East End, the question is why? Various reasons are ordinarily offered. The proximity of Fitzrovia to the retail centres of Oxford Street, Regent Street and surrounding areas, is one reason. The rise in commercial rents of these areas rippled outward, and forced out manufacturing operations in favour of retail. In addition, the East End industry was near where many of its immigrant workers were living, and nearer to the sources of supply—including the Surrey Docks at which imported timber was unloaded from ships. But is this the whole story?

In addition to the differences between locations of the two districts within the city, did differences in the spatial form of the districts themselves help or hinder the persistence of the industry in the districts? We want to suggest that this was the case: that the difference between the local spatial structures of the two areas contributed to the economic difference between them, and that this may also be attributed to the knowledge spillovers of the furniture industry in the two areas. We are not suggesting a deterministic relationship, but instead that the local spatial structure provided affordances that supported or hindered the changes that were otherwise already taking place.

4.1 HISTORICAL DIFFERENCES

4.1.1 FITZROVIA

The modern development of Fitzrovia began in the eighteenth century with the construction of streets of terraced houses originally sold to upper class buyers. Although the area was in between the ‘great estates’ like the Bloomsbury and Grosvenor estates, and was developed in smaller chunks, the pattern of development was based on the typical London terraced house, on an orthogonal plot repeated in identical units along the street. The streets tended to be at right angles to each other, so the pattern of streets is a broken orthogonal grid.

After only a few decades, however, the character of the area began to change as buildings became subdivided and used for multiple tenants including the workshops of small craftsmen, such as those in the furniture trades. In some cases, industrial buildings were built in the back streets and mews but by and large the principal streets to the west of Tottenham Court Road maintained their terraces of Georgian houses. Tottenham Court Road itself changed during the nineteenth century with the construction of larger buildings some of which housed retail stores housing various furniture businesses (Figure 4).

4.1.2 SHOREDITCH

On the other hand, Shoreditch had a pre-Georgian origin with non-orthogonal streets. House plots could be readily transformed to those that were irregular in size and shape. The pattern of streets changed in the 1870s with the construction of Great Eastern Street, a thoroughfare intended to improve connections between the areas where furniture was made, Shoreditch and Bethnal Green, and some of the retail shops where it was sold, in the West End. Along Great Eastern Street were built four- and five-storey warehouse-showroom-workshop buildings that were the headquarters of the wholesaling firms at the centre of the production network.
The resulting streets range from the major thoroughfare of Great Eastern Street down to small lanes and alleys. Shoreditch maintained its status as a centre of the furniture trade well into the twentieth century. Although the centre of the district, the area on which we focused our study, was hardly bombed during the war, by that time many large firms of the industry had already moved away from the centre of London to places where larger sites were available, up the Lea Valley and other places further afield (Figure 4).

Figure 4 - Ordnance Survey maps of Fitzrovia and Shoreditch (1863-1895). Source maps: National Library of Scotland online maps. Photographs by Howard Davis.
5. COMBINING ARCHIVAL RESEARCH WITH GIS-BASED LOCATIONAL ANALYSIS

Our work included the following:

1. The use of advertisements in furniture journals to investigate firms and their premises, an extensive report prepared by English Heritage on the industrial buildings of Shoreditch and Goad’s insurance maps (Figure 5.1).

2. A detailed GIS mapping of land uses related to furniture manufacturing, with data from historic street directories. In order to keep consistency of historical data and maps, we selected the following time periods for each area to investigate the relationship between businesses across a series of time (Figure 5.2):
   - Fitzrovia: 1867, 1889, 1902 and 1920
   - Shoreditch: 1920, 1934 and 1951

3. Space syntax analyses of the two areas, focusing on the properties of the street networks and the distribution of land uses.

4. Combining the historical data and syntax analyses, we use a GIS-based network analyst analysis of location-allocation assessment. The purpose is to examine the possible combinations of knowledge exchange (or spillovers) that different types of businesses have in terms of their proximity. The goal of location-allocation is to locate the businesses in a way that supplies demand points (i.e. other businesses) most efficiently (Figure 5.3).

The method of location-allocation considers each type of business as a ‘facility’ (e.g. a type of business) that links to all related ‘customers’ (i.e. other businesses) in a given area. We statistically compare how quantitatively strong (synaptic weight) is the relationship between one type of business to the rest of the businesses across time. The lines marked in black in figure 5.3 shows an example of how furniture finishers have the strongest link to other businesses, and thus, assessing how much of the furniture finishers were more spatially allocated in relation to other businesses.

This same method was produced by selecting 5 types of businesses: Furniture makers, furniture manufacturers, suppliers, retailers, and finisher. As a result, we can estimate what kinds of businesses were spatially related and more strongly connected to other businesses, hypothesising that certain businesses may be related with within specialised fields (e.g. tool parts with furniture manufacturing) or others more diversified.

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2 The data for Shoreditch includes also from 1852, 1867 and 188. Due to limitations of historical information on the location of businesses in these three time periods, we have excluded these years from our locational analysis (see Figure 5.2).
Figure 5 - Use of data and methodology: (1) Advertisements by English Heritage; Kelly's post office directory (1902) by Tower Hamlets Local History and Archive; Heal's advertisement by Susanna Gooden, A History of Heals (1984). (2) Data collection of businesses colour coded by year. (3, next page) constructing spatial networks with historical data by assessing how different businesses relate to each other in the two areas of London.
6. OBSERVATIONS AND FINDINGS

6.1 MORPHOLOGICAL CHANGES AND FURNITURE INDUSTRY GROWTH

The first observation has to do with plot sizes and plot shapes. There is a greater variety of plot sizes and shapes in Shoreditch than in Fitzrovia. Until the war, this allowed for a greater variety of building sizes, for small old buildings to remain while newer, larger buildings were built. Indeed, buildings in Shoreditch underwent a considerable amount of rebuilding and consolidation of lots. But the Goad’s plans and Ordnance Survey maps suggest that off the main street of Tottenham Court Road itself, the historic building stock of Georgian houses remained until at least the Second World War (Figure 6). While this building stock accommodated craftsmen working in small shops, in buildings that could easily be divided and subdivided, it did not lend itself as well to the establishment of large warehousing firms that were subcontracting with smaller firms. The larger buildings that were built in the alleys and back streets were smaller than new buildings built in Shoreditch, apparently because it was harder to assemble the land. On Tottenham Court Road, large buildings were built to accommodate the large retail firms. These physical changes relate to how the furniture industry evolved in the two areas. For example, Shoreditch increased its suppliers by 9% of all furniture businesses over the 100-year period whilst businesses making wood, metal and glass parts decreased in the same time period (see Figure 6). By comparing the data of directories with the Goad’s plans we found that Shoreditch had 2.5 times more of suppliers (e.g. wood, varnish, cabinet hardware) than Fitzrovia. Shoreditch had also 12% more furniture makers whereas Fitzrovia had more than twice the amount of finishers (e.g. upholsterers, polishers, gilders, carvers) and 5% more of businesses doing finished furniture sales only than Shoreditch.
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Figure 6 - Goad’s insurance plans for Fitzrovia and Shoreditch compared to the historical growth of types of furniture businesses. Goad’s plans by British Library. Photographs by Howard Davis.
6.2 EVIDENCE-BASED ASSESSMENT OF BUSINESS LOCATIONS

The second observation is that the block structure in the two areas is different. In Shoreditch, most streets are continuous, whereas in Fitzrovia many dead-ends are contained within blocks. In space syntax terms, in Fitzrovia just about every block contains street segments in the middle of the block that have very low through-movement (Choice) values, whereas in Shoreditch there are fewer segments of low Choice, along with a variety of Integration values (distances of how close a location is in relation to all other locations). In Fitzrovia, this may have constrained the location of businesses that would otherwise want easy access to most other businesses nearby. In Shoreditch, because choice values were higher, these constraints did not exist as much. In syntactical terms, Shoreditch has a greater variety of spatial integration values among different streets, with even the secondary street segments having medium to high integration values. In Fitzrovia, there was less of a continuous spread of integration values within a radius of 400 metres among street segments. Major streets were consistently more highly integrated and minor streets less so (Figure 7).

![Figure 7 - Frequency counts in relation to number of segments at 400m radius in the street network comparing Shoreditch's and Fitzrovia's spatial integration.](image)

Finally, comparing integration and choice values at a local scale of 400m radius, in Fitzrovia, except for businesses associated with large retailers, many secondary manufacturing businesses are on streets with low integration values. We suggest that this is connected to the fact that in Fitzrovia street like Tottenham Court Road that were highly integrated at a city scale let themselves to retail and commanded retail units. But because of the constricted sites in the back streets, it was hard for businesses in those streets to expand. In Shoreditch on the other hand, businesses are more evenly distributed amongst streets with different integration values but with relatively high local choice values (Figure 8).
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Figure 8 - (top) Syntactical analysis for Fitzrovia and Shoreditch comparing historical land uses and local integration of the street network (NAIN R400m); (below) Integration and Choice (R400m) comparison in relation to all historical time periods for both areas.
6.3 BUSINESS NETWORKS AS KNOWLEDGE NETWORKS: FORMING KNOWLEDGE-BASED ECONOMIES

Based on our previous findings relating syntactical and historical data, we further explore possible connections that may have existed between firms. Figure 9 shows all existing spatial connections that our selected types of businesses - finishers, furniture makers, furniture manufacturers, retailers and suppliers - have with all other firms for each of our study areas. By using the method of location-allocation analysis, the diagrams at the top in Figure 9 show all possible connections for the 5 businesses and within the historical time periods from our data collection. The graphs below of the same figure show how each type of business mapped as networks increased or decreased over time, confirming our previous results that, in Fitzrovia, finished furniture remained over time whereas in Shoreditch furniture manufacturing were still largely present.

The results of mapping spatial knowledge networks between businesses are shown for each case study. Figure 9 shows the urban grain of Fitzrovia showing that suppliers and retailers had more spatial connections to the rest. Finishers and furniture manufacturers have more spatial connections between them which may suggest that similar businesses of finishers like cabinet carvers, upholsters or polishers, may have resulted as spillover effect of the furniture making and manufacturing. In the case of Shoreditch (Figure 10), the outcome was an opposite effect to that of Fitzrovia.

The furniture manufacturing and manufacturing remained with more spatial connections with other businesses over time than retailers and suppliers. Furniture makers, such as cabinet, chair or bedstead makers, are firms that reflect more specialised businesses which require tools, wood parts or specialised manufacturing to produce the furniture. We hypothesise that these spatial relations between the businesses had also its implications on the spatial proximity in Shoreditch. The spatial networks in the urban grain of Shoreditch shows that each of the firms were connected within the same urban block, with the exception of retailers and suppliers. This suggests that knowledge spillovers may imply a more concentrated or 'specialised' forms of businesses to arise establishing in close proximity to each other. The contrary happens in the case of Fitzrovia. The spatial networks of the businesses appear sparser without too much concentration within blocks and would seem that knowledge spillovers are more 'diversified' as a larger amount of suppliers and retailers kept in the area.

Overall, the links between firms across time informs how the two areas evolved as different kinds of knowledge-based economies - Shoreditch as a specialised economy that kept resilient through time and in which innovation may reside in new forms of manufacturing, and Fitzrovia as a more diversified economy in which the furniture industry may have innovated as exchange of knowledge across firms and thereby establishing more retail-oriented businesses in the area.
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Figure 9 - (top) Fitzrovia and Shoreditch showing spatial networks between firms; (below) graphs showing types of businesses in relation to historic time periods.
Figure 10 - FITZROVIA SPATIAL NETWORKS: Maps show the links between finishers, furniture makers, furniture manufacturers, retailers and suppliers spatialized in the local morphology of the study area. Graphs below represent quantitatively the spatial connections between firms.

Figure 11 - FITZROVIA SPATIAL NETWORKS: Maps show the links between finishers, furniture makers, furniture manufacturers, retailers and suppliers spatialized in the local morphology of the study area. Graphs below represent quantitatively the spatial connections between firms.

7. CONCLUSIONS

This research takes place in the context of general increase in interest of the role of urban agglomeration in creating sustainable cities (Neffke et al; Scott and Storper) and its relation to the urban morphology and space syntax fields (Narvaez and Penn 2016; Froy 2016). The organism that is the city is a resilient and networked socio-ecological system—and understanding the historical circumstance that has similarities to emergent features of the contemporary city can help in the development of planning, design and policy for the form of cities in which small industrial shops are beginning to operate again in parallel with the massive firms of the global production system. Particularly in Shoreditch, the nineteenth century furniture industry was structured in a non-hierarchical way, in which relationships among firms were fluid, and in which a variety of small firms persisted over time. Peter Hall’s observation of the greater resilience of the East End is connected to this fluidity, and with the ways in which the physical environment supported it.

In many cities, from London to New York to Detroit to Portland, Oregon, there is a resurgence of industry and much of it has a different form than the vertically organized large manufacturing firms of the nineteenth and twentieth century. It is composed of small firms, with limited
product lines, that deal with other small businesses that are their suppliers and subcontractors. Whilst previous research has argued that ‘flexible accumulation’ (Harvey 1990) presents a different way of organising production and of relations productive units, we argue that the industrial organisation of the furniture industry in the cases of London is not organised along vertical nineteenth and twentieth century developments. We suggest that this research into nineteenth century industrial organisation has parallels with much of the interest we see in urban agglomerations, more typically in the context of the creative economy but also in manufacturing and making. Before the ascendancy of modernist production, we could ask what role did the city play in industrial organisation but in the twenty-first century digital city, and if these agglomerative processes still apply, or are more vertical models being applied as companies go global?
REFERENCES


ABSTRACT
Space syntax theory seems based on the premise of movement as a general capacity of humans enacting their spaces. However, the capacity to move is not an ability equally distributed amongst social actors and; by the same token, mobility is not a homogeneous property affecting spatial behaviour. In this article, we problematize some of these factors brought about by contextual specificities not usually explored in syntactic theory and studies. In unequal urban societies, factors like income and location may be particularly felt, especially among the poorer. The article seeks to understand how mobility is conditioned by grid configuration, location and income – and how these combined factors might have effects on sociability. We developed an approach to capture the daily activities and spatial trajectories of 240 residents of affordable housing complexes in Rio de Janeiro, and a new measure of mobility relating extension and fragmentation in trajectories and number of activities performed. Our results provide evidence of a high dependence of mobility on income. Finally, we examine how different levels of mobility may affect the ability to perform in different spheres of sociability, involving levels of localism and diversity in social ties.

KEYWORDS
Space syntax, social housing, mobility, sociability

1. INTRODUCTION
Space syntax theory asserted a nearly unprecedented level of attention to movement as a condition of social organization and reproduction. Such extraordinary emphasis seems based on the premise of movement as a general capacity of humans enacting their spaces. However, the capacity to move may not be an ability equally distributed amongst social actors. A number of factors might interfere. In unequal urban societies, factors like income and location may be particularly felt, especially among the poorer. If that is the case, mobility cannot be considered a homogeneous property affecting spatial behaviour. In this article, we problematize the conditions of movement by shedding light on social and contextual specificities not usually explored in syntactic studies.

There is also a growing attention to daily activity and movement patterns in sociospatial theory. Beyond usual views of travel behaviour and occasional reassertions of Hägerstrand’s (1970) time-geography, this attention stems specially from exploration of digital location data provided by mobile communication devices (e.g. Gonzales et al, 2008) and social media (Takhteyev et al,
2011; Boettcher and Lee, 2012; Longley et al., 2015). Notwithstanding, there is a growing concern with new, dynamic forms of segregation engendered by different mobilities (Netto and Krafta, 2002; Netto et al., 2015; Wisskinsky et al., 2016), along with renewed emphases on segregation and exposure between socially different people within daily activity patterns (Schnell and Yoav, 2002, 2005; Wong and Shaw, 2011; Farber et al., 2015).

Our work draws upon such an intellectual environment. In this paper, we devise an approach to understand how mobility is conditioned by social and spatial factors such as income, residential location and grid configuration and what its implications to the resident’s spatial behaviour are – and how they might affect people’s sociability. We attempt to capture these factors analysing social characteristics, daily activities and spatial trajectories of residents of a number of affordable housing complexes in Rio de Janeiro, with different income levels. Part of the large-scale national housing programme ‘Minha Casa Minha Vida’ (MCMV), these complexes were for the most part recently built in expansion zones of the city, in North and West Rio – areas highly distant from the main employment centres, presenting serious mobility issues for their residents.

Through these data, we analyse the effects of location, configuration and income on mobility through a new indicator relating pedestrian and transport-based movement based on number of activities, extension and fragmentation in spatial trajectories, measured as a linear fractal dimension through Mandelbrot’s (1983) method. This method allows us to assess the effects of mobility as a complex property, including access to job opportunities, consumption and services, and on observed social behaviour through correlations with the composition of personal social networks of residents. It also aims to offer an analysis of the composition of their networks of relationship and spheres of sociability (i.e. the situations of social contact) – along with the efforts involved in sustaining these networks, and the levels of localism of residents (i.e. the dependence of spatial, residential proximity in order to establish social relationships).

2. RESEARCH CONTEXT

The city of Rio de Janeiro has been subject to a mass production of housing complexes under the MCMV programme. The complexes are mainly located in areas of expansion, following a market logic that seeks cheaper and more distant from the central business district (CBD) lands for construction of the social housing complexes. The Northern zone is an already consolidated area of the city; its population consists of predominantly middle and lower classes. The Western zone is the most recent area of urban expansion – one of the few areas in the city with empty and comparatively cheap land, allowing opportunities for building massive social housing complexes (SHC). Both areas have serious problems of mobility and access to the rest of the city.

The location of SHCs in areas away from large centres of employment, study and leisure may have a negative effect on mobility, with severe implications for residents. Greater distances to commute everyday generate financial and temporal burden on actors, thus potentially limiting the number of activities that can be performed throughout the day.

For a better understanding of how location and income can affect the daily movements of these residents, we collected data on the routines of 240 residents through interviews performed in twelve SHCs located in North and West Rio. Importantly, this housing programme is composed of three distinct income levels, from low to middle-low income, the group 1 with incomes up until USD $669,46, the second group up until $1297,07 and group 3 up until $2092,051. In addition to the daily routines, we also collected information on the personal social networks of residents, gathering the location and circumstance of social contact with up to ten friends. These data offer us the possibility of assessing aspects of spatial behaviour, such as daily trajectories and mobility levels, and comparing them with social variables such as income and variables of sociability, in order to understand how they interact in urban life. Figure 1 shows location and syntactic analyses of Rio de Janeiro’s grid generated on Depthmap.

1 Values converted from Brazilian Reals to United States Dollars, the quotation used was the first of the 2014 on 02/01.
3. SPATIAL BEHAVIOUR

Through data collected in interviews, we were able to ascertain the impacts of the SHC' location on the spatial behaviour of its residents. We gathered information on income, places of work, leisure, medical services and consumption, and the location of ten friends of interviewees, as a way to look into the strong ties within their personal social networks (Granovetter, 1973). Our spatial behaviour analysis focuses on the complete trajectories of interviewees on the day before interviews, and approaches the city as a spatial network of streets plus places of activity. Activities analysed have well defined roles in people's routines (such as work and actions involved in leisure and daily consumption). Residents' trajectories may involve pedestrian movement, public transport or private vehicles, and were analysed the trajectories from twelve places of origin.

These trajectories are traces of people's actual presence in space. Mapping these paths could offer a good idea of how residents spatialise their everyday actions, and how residential location and patterns of mobility might shape their actions in the city. We consider the possibility that modes of transport used by the actors may have as much influence on mobility as the street network of that articulate the places of activity. Our initial hypothesis is that factors such as residential location and income may have roles in shaping the spatial behaviour and mobility of interviewees. Moreover, this analysis will allow us to evaluate the effect of the new residential location on the composition of residents' personal social networks. The representation of
Figure 2 - Spatial behaviour of SHC residents in Rio de Janeiro, according to transport modes and income groups.
trajectories allows the visualisation of potentially different spatial behaviours, and may offer hints into forms of mobility, along with the recognition of the role of residential location in the viability of residents’ routines and spatial features of their social lives (figures 2 and 3).

Comparing trajectories on the spatial fabric of Rio de Janeiro with the integration and choice analyses (figure 1), we can observe that the trajectories of the lower income group (income 1) seem to concentrate on the main accessibility axes of Rio. One of the possible reasons for this behaviour is the mode of transportation. Lower income actors usually are more dependents
of the public transport. We estimated thresholds from which the ownership of private vehicle becomes more common. We found a threshold of $209.21 per capita, from which families are likely to own at least one private car (figure 4). For people who live in areas with low accessibility, a private vehicle can have substantial impact on individual mobilities.

As income increases, so does the ownership of private vehicles, which allows actors to use alternate routes and streets outside the main accessibility axes of the city. We will be able to verify how much this is the case later on, through the precise measurement of the fractal dimension of these different trajectories. In fact, a wide range of information can be acquired from mapping actual trajectories: the influence of the housing complexes’ location on distances to work, services and friends, the levels of vehicle dependency, and the need for travels beyond the immediate residential neighbourhood to carry out activities and find services.

The analysis of median distances travelled by residents indicates that housing complexes localised in West Rio induce greater distances, offering unfavourable conditions of access to almost all analysed destinations, such as the CBD, work, retail activities, services (with exception to healthcare services) and friends. Table 1 shows that residents from the lowest income live in complexes more distant to the city’s centre (the central business district-CBD), and reallocated themselves (to the housing complexes) from more distant neighbourhoods.

Table 1 - Median distances (Km) travelled by different income groups.

<table>
<thead>
<tr>
<th>Income groups</th>
<th>Home-CBD</th>
<th>Home-Previous Neighbourhood</th>
<th>Home-Work</th>
<th>Home-Retail</th>
<th>Home-Health Care</th>
<th>Home-Leisure</th>
<th>Home-Friends</th>
<th>Work-CBD</th>
<th>Pedestrian trajectories</th>
<th>Public Transport trajectories</th>
<th>Private Vehicle trajectories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>31.8</td>
<td>14.2</td>
<td>7.9</td>
<td>5.8</td>
<td>4.6</td>
<td>6.2</td>
<td>4.2</td>
<td>18.19</td>
<td>2.7</td>
<td>1.8</td>
<td>22.1</td>
</tr>
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<td>31.8</td>
<td>11.9</td>
<td>7.0</td>
<td>2.3</td>
<td>4.6</td>
<td>5.5</td>
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<td>1.6</td>
<td>26.3</td>
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</tbody>
</table>

Pedestrian trajectories are remarkable similar in extension for all income groups. Counterintuitively, higher income residents tend to deal with greater distances to commute. A great part of their daily routines tends to happen around these two places (home work) and along the trajectories between these places. Another condition involves the level of dispersion of work location for different income groups. We analysed distances from work locations to the city’s CBD (namely the intersection point of the two most integrated streets, Presidente Vargas Avenue and Rio Branco Avenue). Absolute distances and maps of work density (figure 5) suggest different dispersion levels of work locations for different income groups. The CBD is an

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2 Of the 290 interviews that were considered at this stage, 100 belong to income group 1, 61 to income group 2, and 118 to income group 3. Eleven interviewees declared that they would rather not inform their income.
important location for higher income, and its importance decreases with income.

One of the possible explanations for this is that jobs requiring greater specialisation tend to be located in the city’s major employment centres, while jobs with lesser degrees of specialisation may spread more easily and be found throughout the city. Another factor is that income can limit the ability to commute great distances, thus reducing the range of work search to locations closer to home. Higher income residents also deal with greater distances to retail, leisure activities and healthcare services. They are able to keep friends in more distant places from their new residential location.

If on the one hand journeys to work are shorter for lower income residents, on the other hand they are more removed from their previous residential locations, in Rio’s many favelas (table 1). This suggests the potential for disruption in previously established social relationships.
dependent on residential proximity, as we shall see below. Low-income residents are also likely to use healthcare facilities closer to home, which suggests that higher income residents are able to choose farther facilities according to preferences and higher mobility. A higher income might offer more capacity to look for specific services. We shall confirm the possibility of differences in mobility levels in the next section.

4. RELATING INCOME AND MOBILITY

In order to ascertain the role of mobility in spatial behaviour and sociability, we must first turn to a definition of mobility. In fact, the concept of mobility extends over a very wide range of urban studies. Urry (2002) defines five types of interdependent mobilities able to form and reform social relationships and networks:

- corporeal travel of people for work, leisure, family life, pleasure, migration and escape;
- physical movement of objects delivered to producers, consumers and retailers;
- imaginative travel elsewhere through images of places and peoples upon TV (1 billion worldwide);
- virtual travel often in real time on the internet so transcending geographical and social distance;
- communicative travel through person-to-person messages via letters, telephone, fax and mobile.

For the purpose of this work, we will deal with the first type of mobility defined by Urry, the corporeal travel of people. According to Urry, and with interesting alignments with space syntax theory (e.g. Hillier and Hanson, 1984; Hillier et al, 1993), what drives our travels, inside or outside the urban fabric, is the need for co-presence in space, vital for us to maintain a network of interpersonal social relationships. With a starting point in Urry’s premises and in convergence with syntactic substantive emphases, we can define mobility as the capacity of an individual to generate trajectories that result in co-presence and activities in urban space.

Now studies that seek to establish relations between space and sociability (e.g. Putnam, 1993; Marques, 2015) have usually focused on territorial segregation as an obstacle to the development of larger, more diverse and less homophilic social networks. These works are mostly concentrated on residential location, then (non-statistically) correlated with number of spheres of sociability in one’s personal social network. In turn, Linton Freeman’s (1978) innovative view of segregation as ‘restrictions on interaction’ suggests that interpersonal contacts require more than a static territory. They involve daily interactions throughout the city fabric, and exposition to diverse situations where social relationships can be developed.

Furthermore, Freeman gives us an insight into how we can link space and social networks. Mobility can be seen as a factor that creates the possibility for co-presence in urban space and can contribute to reduce the socio-spatial segregation, helping people to overcome restrictions of interaction with those from different social background (Netto and Krafta, 2001; Netto et al, 2015).

\[ N = r^{1-D} \]

Where \( N \) is the number of segments, \( r \) is the scale factor and \( D \) is the fractal dimension of trajectories.

We spatialised the trajectories collected in the interviews using a GIS (geographic information system) software. We suggest to use a measure of mobility composed of (i) extent, (ii) number of activities performed during the day, and (iii) fragmentation – the number of street segments used by the residents. The fragmentation of trajectories is analysed through its linear fractal dimension and the Mandelbrot method (1983).
These trajectories are converted into pixels, with increasing detail according to the scale. We opted for a 0.7m pixel and a scaling factor of five times \((r_1e = 0.7, 3.5, 17.5, 87.5, 437.5, 2187.5)\). As changes between scales follow a progressive proportion, we added a proportionality constant \((K)\) to the equation: \(n = Kr^{1-D}\) interpreted through natural logarithm \(\log n = \log K + (1 - D) \log r\) where \(n\) is the number of pixels in each resolution scale and \(r\) is the scaling factor. Combining the fractal dimension of trajectories and the number of daily activities as factors leads us to the following measure of mobility:

Through this measure, we could quantify the mobility of residents as a form of evaluation of how they perform their routines in city space. Figure 6 shows results for the extension of paths, number of activities, number of segments and the combined measure of personal mobility, according to the housing programme’s income levels\(^3\).

![Figure 6 - Work density by income groups.](image)

Results show that the lower income group has levels of extension, number of segments, number of activities and mobility lower than the other income groups. However, the variation between the two higher income groups for mobility is not large – due to similarities in the number of activities performed. One possible explanation for this is that both groups are above the income threshold that allows them to move around the city and join activities of consumption and leisure. Summing up, our analysis points to substantial differences in spatial reach for residents of different incomes groups.

\(^3\)The box plot graph shows the dimension of data or their spread. The line inside the boxes is the average. The lower the height of the boxes, the more concentrated and similar are the observed intensities. The points above the boxes are discrepancies, i.e. observations very different from the others.
• Mobility is likely to increase with income.
• The extension of pedestrian paths is very similar for the three income groups.
• The higher income group tends to work closer to the city’s CBD. They also benefit the most from new location as far as proximity to the previous location is concerned.
• The lower the income, the greater is the distance from the residents’ new location to their previous neighbourhoods. This item can have effects on residents’ social network, as we shall assess from now on.

5. THE EFFECTS OF MOBILITY ON SOCIABILITY

We have seen that spatial behaviour has to do with the conditions of residents of affordable housing complexes to build and maintain their networks of personal relationships. These relationships form what has been defined since the 1950’s as ‘social networks’ (see Wasserman, 1994; Lin, 2005). The composition of social networks is far from a trivial, inconsequent affair. There is an established understanding in the literature that the diversity of ties and number of nodes in personal networks are a key part of one’s ‘social capital’.

In turn, social capital can be defined as the aggregate of actual and potential resources linked to a durable network of relationships of mutual acquaintance or recognition (Bourdieu, 1986), and to (symbolic and material) resources accumulated and opportunities created through such relationships (Coleman, 1988). Networks and social capital are constructions that take effort and time. Basic characteristics of networks associated with social field of origin of actors may be explored through the concept of ‘spheres of sociability’. In theory, the greater the number of relationships and the more diverse of their spheres are, the greater the potential for opportunities and mutual support between actors.

Research in Brazil has found strong links between residential location, segregation and the composition of personal relationships (Holanda, 2000; Marques, 2015; Netto et al, 2015). Lower-income actors rely more heavily on their neighbourhood to generate personal networks. The hypothesis that naturally arises is that moving to the housing complexes has an impact on personal social networks of residents. As a matter of fact, this would be expected for actors of any income profile – but in the case of smaller incomes, impacts could be stronger, due to lower mobility. Figure 7 brings our findings on the composition of sociability in different income groups.

As lower-income actors tend to have lower mobility, neighbourhood relations constitute a large part of their personal networks. For these reasons, a new location means that actors...
may suddenly see themselves partially deprived of their social networks, along with difficulties in maintaining older (and now more distant) friends. Friendships created through work and learning situations tend to increase with income. These two categories have more chances of reducing the homophily levels (similarity between actors), since they lead to an increase in diversity of the spheres of sociability and opportunities of contact with people from social fields and classes distinct from those of the resident.

The proportion of relationships on the neighbourhood gives us an insight into the spatial composition of these relationships; the relationships from the current neighbourhood have a greater presence in the friendships from the income group 1, and decreases as the income rises (figure 7). This fact might indicate a greater dependence of the neighbourhood for the individuals with lower incomes, or a higher level of localism in their networks. Our survey of activity and friendship distances (table 1) confirm these tendencies, demonstrating that the residents with lower incomes maintain friendships and perform activities closer to home.

The analysis shows significant difference in the composition of the relationships of people from different income groups. Moving from distant neighbourhoods to the new complexes might have had an impact in these relationships, since as we have seen the neighbourhood has a great importance for the lower incomes.

A reasonable hypothesis is that there is a gradual decrease in the contact with friends from the previous neighbourhoods, induced by the new distance and mobility, which varies according to income. Higher income actors may experience less rupture of the spatial and temporal fabric that structures the social network of the residents. There would be a decrease in the number of members from the older neighbourhood, with impacts on opportunities for activities and daily support (capital reduction). However, in a new stage, we would have a progressive increase of new members by the proximity in the new neighbourhood, with possible increase of social capital. In fact, what our data points up to date is a renewal of the social network of the residents, with the growing presence of friends mainly within the housing complex. The new location is already felt in the social networks of residents living less than two years in their new homes.

Two concepts help us to make sense of patterns of relation between income, location, mobility and sociability:

(a) Levels of localism: the location of members of personal networks and the places of activity of each resident can reveal the level of dependence of proximity to establish social relationships. We seek to understand possible impacts on residents and their efforts to keep their personal networks after moving to the new complexes.

(b) Diversity and homophily in personal networks: The sociability of the different income groups have great differences on its spheres of sociability that form their social network, these differences show their level of Localism (dependence on proximity in the space) and homophily. Through the interviews, we collected data that shows the dominant presence of the

\[
S_i = \frac{-\sum_{j=1}^{k} (p_{ji})(ln P_{ji})}{ln k}
\]

Where: \(S_i\) = entropy index in friendship \(i\), \(P_{ji}\) = proportion occupied by spheres \(j\) in friendships \(i\) or proportion of units with spheres \(j\), \(K\) = number of spheres, \(ln\) = natural logarithm

neighbourhood in the relationships of the residents, and inside the complexes for actors from the lower income group. This dominance of neighbourhood based relationships decreases as income increases, showing evidence of an impact of the income on the localism of the residents’ relationships (figure 7).
Table 2 - Spheres of sociability of different income groups.

<table>
<thead>
<tr>
<th></th>
<th>Income</th>
<th>Fractal Dimension</th>
<th>Mobility</th>
<th>Social Diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Income</td>
<td>1</td>
<td>0.21</td>
<td>0.18</td>
<td>0.56</td>
</tr>
<tr>
<td>p-value</td>
<td>1</td>
<td>0.001</td>
<td>0.008</td>
<td>0.000</td>
</tr>
<tr>
<td>Fractal Dimension</td>
<td>0.21</td>
<td>1</td>
<td>0.56</td>
<td>0.23</td>
</tr>
<tr>
<td>p-value</td>
<td>0.001</td>
<td>1</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Mobility</td>
<td>0.18</td>
<td>0.56</td>
<td>1</td>
<td>0.18</td>
</tr>
<tr>
<td>p-value</td>
<td>0.008</td>
<td>0.000</td>
<td>1</td>
<td>0.005</td>
</tr>
<tr>
<td>Social diversity</td>
<td>0.56</td>
<td>0.23</td>
<td>0.18</td>
<td>1</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
<td>0.005</td>
<td>1</td>
</tr>
</tbody>
</table>

In order to assess the level of diversity in personal networks, we used Shannon’s information entropy (Shannon, 1948), considering nine spheres of sociability collected through interviews: work, leisure, current neighbourhood, learning activities, family, friends in common, religious institutions, former neighbourhood and ‘others’.

We were able to verify correlations between the diversity of personal relationship, income, fractal dimension of trajectories and the mobility of each actor. The table below illustrates the correlation matrix (by Spearman’s method) of these variables.

The correlation matrix shows positive correlations between income, diversity and the fractal dimension of paths, suggesting associations between the mobility and the diversification of social relationships.

6. CONCLUSIONS

Our approach is intended to assess relations between patterns of space, spatial behaviour and aspects of social life. We have seen that the mobility of the residents is closely related to income (figure 6). Restrictions in mobility found for residents in affordable housing complexes corroborates patterns observed by Holanda (2000), Marques (2015) and Netto et al (2015) regarding the effects of spatial segregation on the diversity of social ties in other Brazilian cities. We have also observed that the grid configuration has an impact on these individuals’ mobility, tending to limit the trajectories of lower income actors to the city’s axial lines with higher integration.

The lower mobility of actors from low-income groups might also have relations to their job opportunities. As we have seen, lower income groups tend to have their jobs closer to home, whereas higher income actors tend to have their jobs closer to the CBD. Possible interpretations of these behaviours may include higher levels of specialisation around jobs spatially concentrated in the CBD, along with higher mobility expanding possibilities in the search for jobs.

Higher income residents are also likely to have more benefits from residential location: their homes tend to be located closer to the CBD. Actors from higher income groups also reallocate themselves to complexes closer to their former neighbourhood, potentialising their contact with friends in that sphere of sociability and allowing them to preserve their original social networks, a key factor of social capital.
In this sense, our analysis of spheres of sociability also shows significantly differences between income groups. Higher income group shows less dependence on proximity to form friendships and constitute their social network. Lower income actors have a greater proportion of relationships formed through the neighbourhood, demonstrating higher dependence on physical proximity – and localism. Unsurprisingly, levels of homophily also vary according to income and mobility. Residents with higher incomes and greater mobility tend to produce relationships at broader spatial scales, especially with actors who share their mobilities, increasing the chances of contact between their personal networks. Higher income residents are also likely to have more relationships related to study and work, which tends to reduce homophily levels.

Finally, we have found evidences of an overall decline in contacts with members of the social network in previous neighbourhood – along with evidences of addition of relationships within the new neighbourhood, adding whole new collections to personal networks, with potential effects still to be estimated.
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FINDING THE SECRET FORMULA

How can we quantitatively understand cities’ growth, based on their street network structure?

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ABSTRACT

Cities are complex, perhaps one of the most complex kinds of structure created by humans. Some cities have been planned top-down to a large extent while others have grown organically on their own. The outcome of these planning and growth processes are the various morphological building and street patterns seen in cities. There are strong reasons to believe that the street system in a city has a crucial effect on land use and building development (Hillier, 1996). It is therefore essential to understand the complex street networks in our cities. This is not only to categorize cities but also to be able to switch-over our transport system towards a higher degree of sustainability.

Despite extensive research in the fields of urban planning and urban history, there are still very few consistent ways of quantitatively describing and classifying cities. The perspectives used in research so far have mainly categorized them based on visual judgements of their morphology (Kostof & Tobias, 1991). It is problematic that classifications are mainly based on subjective judgement and lack a quantitative measure. To understand cities and their characteristics, it is necessary to find methods and measures that can describe these characteristics and also be suitable for comparisons between cities.

By using space syntax methods, it is possible to find measures and properties of the cities’ street networks, which sometimes seems to exhibit patterns with scale free properties (Jiang, 2007). Thanks to recent progress in the field of complexity studies, it is now also possible to test if and to which degree a network has scale free properties. One commonly used approach is to test whether the distribution of a certain property in a collection of elements fit a power law distribution (Clauset et al., 2009).

The results of this study show that the degree distribution for a city’s street network seems to fit a power law for cities grown organically. On the other hand, cities that are planned to a large extent do not have that good fit. This result seems sound, since a distribution that fits a power law is a signature of a multiplicative growth processes. Another interesting finding following this result, is that this way of quantitatively classifying cities seems to correlate well with earlier attempts of qualitative morphological classification.

KEYWORDS  
Space syntax, power law, organic growth, spatial morphology, degree distribution
1. INTRODUCTION

Cities have been a very important part of the human civilization since agriculture-based society emerged. They have been built independently from each other in different parts of the world in varying cultures. A very basic dichotomy’s way of classifying cities is by their growth and resulting morphological pattern: organic cities have grown gradually, versus planned cities that have grown from larger planning interventions (Hillier, 1996). Some cities are entirely planned in one sweep, while others have mainly grown organically, and often, these processes have alternated back and forth over time (Kostof & Tobias, 1991).

Although this is not a distinct dichotomy, but rather a question of more or less planning resulting in different patterns in different areas (Kostof & Tobias, 1991), it is still used as a predominant description of cities. Another way of describing this dichotomy is using the concepts of bottom up growth (organic) versus top-down growth (planned) (Batty, 2013). A peculiar aspect is that these organic patterns have been seen as desirable in cities, and therefore efforts to mimic them have often been used in planning (Kostof & Tobias, 1991). Despite research on the topic, there are still few consistent ways of quantitatively classifying and describing these properties and characteristics of morphologic patterns (Volchenkov & Blanchard, 2008). Since cities are such an important part of society and this dichotomy’s categorization – organic versus planned - is often used as fundamental explanation, it is problematic that there are still few consistent ways to quantify it.

2. BACKGROUND

Urban areas have been studied as an academic discipline for a long time, but is has often been done in qualitative studies based on perceived patterns (Kostof & Tobias, 1991). Around the 1980’s a new methodology for quantitative analysis of city structures was developed, are called space syntax (Hillier & Hanson, 1984). As the name indicates it is about the analysis of the configuration of spaces: architectural, urban streets or open spaces. Spatial configuration is best explained as how spaces, or in the case of cities usually streets, are related to and connected with each other (Hillier, 1996; Marshall, 2015). A basic concept of space syntax is that it analyses the topology of the street network, and therefore leaves out metric information (Hillier, 1999).

Parallel to this research, other research groups started in the 1990’s to analyse cities by growth simulations, often using cellular automata (Batty & Longley, 1994). In this field, cities are often claimed to be fractal, which means that certain measures have scale free properties. This is claimed to be the result of a bottom up growth, which mean that organic cities might by analogy be called fractal.

During the last ten to fifteen years, parallel to the growth of space syntax as a research field, another important field of research that has been rapidly evolving is network science (Watts, 2004). As computers have become more powerful, new methods appeared for calculating network properties in large networks, such as small world network properties and scale free properties. Those properties are based on new theories and methods (Watts & Strogatz, 1998) discovered during the past twenty years. Topological analysis is the fundamental model for this new scientific paradigm of network science, where many kinds of networks are studied, including city street networks (Barthélemy, 2011) (Watts, 2004). This offers the possibility to study cities from an entire new perspective.

Based on this progress on complex network analysis in general, new theories and methods for analysing road and street network patterns have been developed within the research field of space syntax (Jiang et al., 1999; Porta, S. et al., 2006; Jiang, 2007). These methods use the results from a space syntax analysis and thereafter analyse various properties, both individual measures and statistical distributions (Jiang, 2007; Volchenkov & Blanchard, 2008; Shpuza, 2017). These elaborations of the space syntax research field, thanks to the network science field in general, might enable the quantification of cities in a better way.
2.1 EARLIER WORK

Some efforts to find properties for cities as a whole have been made (Crucitti, P. et al., 2006; Porta, S. et al., 2006; Porta, Sergio et al., 2006; Jiang, 2007; Volchenkov & Blanchard, 2008; Shpuza, 2014), although many of these studies were done on a small sample area or on few cities that make the results harder to use for general conclusions. The results are also diverging and sometimes incompatible. It has been shown in some studies that various network measures like degree, betweenness and other centrality measures, reveal a scale free behaviour in many cities (Porta, Sergio et al., 2006; Jiang, 2007; Volchenkov & Blanchard, 2008). Other studies refute this and have shown that there are differences and exceptions from these patterns (Jiang & Claramunt, 2004; Crucitti, Paolo et al., 2006; Porta, S. et al., 2006). To further support or refute these claims, a more extensive analysis is needed. The results of this earlier work can be discussed with the results from the present study, even though the preconditions and methods are not identical.

2.2 AIM

The aim of this study is to uncover measures calculated from the street network’s topology in a number of cities to find out whether there are universal patterns as claimed in earlier studies, or if they vary as other studies (referred to in 1.2) suggest. That could explain the contradictory results claimed in these studies.

The hypothesis is that these patterns are not universal, but rather depend on whether the cities are organic or planned. If that holds true, then these measures might be used for further analysis and categorization of cities, as well as used to evaluate plans and extend our understanding of cities in general.

3. THEORETICAL FRAMEWORK AND LIMITATIONS

3.1 NETWORK ANALYSIS METHOD

When the space syntax research field started in the 1980’s, the main element of analysis of street configuration was the axial line (Hillier & Hanson, 1984). An axial line is an unobstructed line of sight. To analyze an area or a city an axial map is created, made of the fewest and longest unobstructed lines of sight, which are the axial lines (Hillier, 1996). This method has been dominating the research field until early 2000’s, when efforts were made to integrate space syntax in ordinary GIS research and make it possible to utilize the more common road centerline maps (Jiang et al., 1999; Thomson, 2003; Turner, 2007). Axial line analysis requires the manual digitising of the streets (Hillier, 1996), which would be too time consuming for this extensive quantitative analysis. Therefore the use of a method based on readily available road centerlines is necessary. To analyse the degree centrality of the street network, it is necessary to use a method that renders a discrete result for each street. That rules out the street segment based angular analysis models widely used today (Turner, 2007).

One of the methods developed in this effort to replace axial lines as the basic spatial element when using road centerline maps is the concept of Natural Roads (Jiang et al., 2008), similar to strokes (Thomson, 2003) and continuity lines (Figueiredo & Amorim, 2005). These concepts are based on the Gestalt principle of good continuation (Jiang, 2007). Over the years, steps have been taken to elaborate this method, in order to improve it in revealing the structure of the city (Jiang & Liu, 2009). It has a consistent response to boundary effects (Gil, 2016). Its correlation with pedestrian and vehicular movement is on par with the other major methods in the space syntax research field, such as angular segment analysis and axial lines (Jiang, 2009; Jiang & Liu, 2009), which also supports its validity. All together this makes the Natural Roads method the most suitable for this study.
3.2 DEGREE DISTRIBUTION AND POWER LAW FITTING

The most basic measure obtained in space syntax calculations is called connectivity, i.e. the number, per street, of connections with other streets, also called degree centrality in network science studies. When studying the distribution of degree, often a certain pattern occurs. This pattern sometimes seems to follow a power law distribution, which has scale free properties (Porta, Sergio et al., 2006; Jiang, 2007). In other fields of network research, such as sociological studies of connections between people, flight connections or power grid structures, the same pattern occurs, namely that there are far more low connected elements than highly connected ones (Barabasi & Albert, 1999; Clauset et al., 2009). This aspect of urban studies has not been extensively researched, and seems interesting and enables the possibility of new discoveries.

3.3 ASSUMPTIONS IN THIS STUDY

Many studies in network science rely on degree centrality as the single measure of distribution to test for power law fitting (Clauset et al., 2009) (Barabasi & Albert, 1999; Volchenkov & Blanchard, 2008). There is a large variety of other centrality measures that can be calculated. They offer a possible direction of investigation in future studies, but to make the results of this study easily comparable with other studies, also from other network research fields, only degree will be used. It is a question of not getting stuck in complicated results, where there are too many variables involved to reach clear conclusions.

A parameter that has to be taken into consideration is the extent of the studied areas. It could be argued that larger study areas are better due to the larger amount of analyzed data. On the other hand, many cities with organic patterns are often small or their areas with organic patterns are small (since these are often the oldest areas). In this study, the main goal is to capture the structure of the city that is the result of its historical growth to get an indication of whether the hypothesis might be true. This means that this study does not require large amounts of data to reveal interesting results. Therefore, a circular sample area with a radius of 8 km has been used, also to make cities with different sizes more comparable. These are centered (where applicable) on the historical starting point of the city, like Île de la Cité in Paris. In some cases, one can argue that this delimitation is arbitrary, while in other cases, like Venice, the city limits are very clear.

Having more cities in the study could be beneficial, but since the aim is not to reach a conclusive answer, but rather open up the path for new theories, the number of cities chosen (10) can be considered sufficient. This selection should be seen as a starting point for further and deeper studies of both large cities and smaller neighborhoods. Studying parameters of cities over time as done by (Shpuza, 2014, 2017) could maybe also reveal interesting results. It seems unlikely that the studied properties are constant over time.

4. DATASETS AND METHODS

4.1 STUDY OBJECTS

There are no standardised and consistent ways of describing cities, therefore the selection will be somewhat arbitrary and subject of discussion. Since the aim of this study is to find patterns depending mostly on growth processes, the selection is mainly based on earlier attempts of classifying cities (Kostof & Tobias, 1991; Batty & Longley, 1994; Hillier, 1996). The other criteria for the selection have been chosen in order to have variations, to try to confirm or refute the existence of universal patterns.

The first and foremost criterion is degree of planning or self-organization, in order to have a somewhat balanced collection between organic and planned cities. As second criterion, the dominant culture that has shaped the city morphology is chosen. Different cultures may play a large role in the cities’ street network structure (Hillier, 1996). This is probably because of different ways of social structure and organization (Kostof & Tobias, 1991). In various cultures, there have been different ways of living the daily life and performing social interactions. Then,
geographic location is chosen as third criterion, since the preconditions differ considerably in different parts of the world, namely the geology, climate, building materials supply and cost. Intuitively, this should affect the structure of the street network. The cities in this study are chosen from different continents or continental areas. Finally, age of the city can also play a role in that organic city evolution takes long time whereas building a planned city can be done quite fast in comparison.

Based on these criteria, ten cities have been chosen for this study (Table 1). Excerpts of their street network are shown in figure 1.

<table>
<thead>
<tr>
<th>City</th>
<th>Degree of planning</th>
<th>Shaped by culture and religion</th>
<th>Location</th>
<th>Age</th>
<th>Geographical characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rio de Janeiro</td>
<td>Many self-organized favelas</td>
<td>Catholic South American</td>
<td>Brazil</td>
<td>Modern (60's)</td>
<td>Coastal city</td>
</tr>
<tr>
<td>Venice</td>
<td>Self-organized villages grown together</td>
<td>Catholic European</td>
<td>Europe</td>
<td>Middle age</td>
<td>Several islands</td>
</tr>
<tr>
<td>Damascus</td>
<td>Old roman city organically, reshaped when under Arab government</td>
<td>Originally roman, later Arabic/Islamic</td>
<td>Middle east</td>
<td>Roman age</td>
<td>Desert/plain</td>
</tr>
<tr>
<td>London</td>
<td>Low, self-organizing</td>
<td>Anglo-Saxon, Lutheran</td>
<td>Europe</td>
<td>Middle age</td>
<td>River city</td>
</tr>
<tr>
<td>Tokyo</td>
<td>Low, self-organizing</td>
<td>Japanese all the time, although became capital later</td>
<td>Eastern Asia</td>
<td>Middle age</td>
<td>Coastal city</td>
</tr>
<tr>
<td>Beijing</td>
<td>High, since it became capital</td>
<td>Chinese all the time, although it became capital later</td>
<td>Eastern Asia</td>
<td>Antiquity</td>
<td>Topographical constraints</td>
</tr>
<tr>
<td>Moscow</td>
<td>High, as an expression of power</td>
<td>Russian Orthodox, capital all the time</td>
<td>Russia</td>
<td>Middle ages</td>
<td>River city</td>
</tr>
<tr>
<td>New York</td>
<td>High, the original grid is virtually unchanged</td>
<td>American all the time.</td>
<td>North America</td>
<td>About 1600.</td>
<td>Several islands</td>
</tr>
<tr>
<td>Brasilia</td>
<td>Very high, entire city planned at once</td>
<td>Very new, built as Capital</td>
<td>Brazil</td>
<td>60's</td>
<td>Exploited jungle</td>
</tr>
<tr>
<td>Paris</td>
<td>High, since both the Baroque planning and Haussmann’s boulevards.</td>
<td>Catholic European</td>
<td>Europe</td>
<td>Middle age</td>
<td>River city</td>
</tr>
</tbody>
</table>

Table 1 - Summary of properties for the studied cities
4.2 SOURCE OF STREET NETWORK DATA

The street network of the studied cities is the main study object. Therefore, it is essential to use a reliable data source. To make such a worldwide comparison, it is essential for such a common data source to have the same kind of data classification and collection process. Publication restrictions and copyright issues make usage of official land surveys or proprietary navigational street data (e.g. TomTom, Navteq, Google) hard. Instead, Open Street Map (OSM) was used as source for the street networks (© OpenStreetMap contributors). OSM is an initiative to create public domain map data. It is open for anyone to edit and create new features in the map. It has a worldwide coverage, although the level of detail might differ between different areas.

There has been some debate about OSM regarding its data quality, since anyone can edit it. Research has suggested that the errors in this map are on par with those in other maps from authoritative sources (Haklay, 2010; Dhanani et al., 2012). Therefore, the benefits of being able to use a common map source for all the cities in this study, without copyright or other legal restrictions, outweigh the possible data quality drawbacks of using OSM.

Figure 1 - The street networks of the studied cities
4.3 SOFTWARE USED IN THE ANALYSIS

To do an automated data validation and analysis, several pieces of software are needed. Firstly, the FME software is used for cleaning and validating the data. Then, the software Axwoman (Jiang, 2015) for ArcGIS is used to create natural roads and calculate degree centrality. The degree distribution of the streets (from ArcGIS) is processed in MATLAB (MathWorks, 2014) for each city. This analysis uses the additional software package “Power-law Distributions in Empirical Data” (Clauset, 2007) in MATLAB. Further tests are carried out using the poweRlaw package in R (Gillespie, 2015), which is also based on the work by Clauset. Finally, Microsoft Excel is used to collect and visualize the statistical results. The use of several pieces of software has been necessary to reach the desired results, although it would be a simpler process if a single application with all the capabilities existed.

4.4 METHODOLOGICAL PROCESS

The analysis method starts with the download of OSM data in shape file format from the internet site www.geofabrik.de. After the data download, a series of extraction, cleaning and validation operations are performed in FME to enable further processing of the data set with Axwoman. Clipping is the first step, in order to extract the streets in the 8km study area and discard all other streets in the data set. The next step is to project the map with a projected coordinate system. In this study the WGS84 World Mercator projection is used. The next cleaning step is to break all the street lines at every intersection. This is because some street segments are continuous across intersections, which renders it impossible to make the natural streets interconnection algorithm to work. Finally, any isolated single streets or "islands" of streets are identified and deleted. This is necessary, as the network has to be a single connected component for this analysis to work. When this data validation step is completed, the next step is the analysis.

The next step is to generate the natural roads. This is done by joining the street segments at the intersections according to the “every best fit” algorithm in Axwoman with the threshold angle of 45 degrees (Jiang et al., 2008). The result is a network of natural roads that can be seen in figure 2. Once the natural roads have been created, Axwoman is used to calculate degree centrality, which is then exported for the final statistical analysis.

The degree centrality results of natural roads are imported into MATLAB for statistical analysis with “Power-law Distributions in Empirical Data” (Clauset, 2007). The analysis checks if the degree distribution seems to fit a power law distribution. The first step is to do a power law fit, where a possible x-min and alpha values are calculated. The next step is to test whether the data can fit a power law doing a Smirnoff-Kolmogorov test. This test generates many samples based on an ideal power law distribution with the x-min and alpha values derived from the distribution under test. Then, these samples are compared to the distribution being tested and a regression analysis is done to derive a significance test. If the resulting p-value is above 0.1, the distribution has a large probability of being a power law. The results of these tests (the p-value, x-min and alpha) are then used in the final analysis and judgement.

When all these measures are extracted, it is time to do a qualitative comparison between the cities to see if their quantitative properties have some relation to their qualitative morphological characteristics.

1 FME software package, https://www.safe.com/fme/fme-desktop/
FINDING THE SECRET FORMULA

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Figure 2 - The cities' dual graph network coloured after degree distribution, red is high.
5. RESULTS

5.1 DERIVED PARAMETERS OF DEGREE DISTRIBUTION

The final results of the geographical, topological and statistical calculations for each city are shown below in Table 2. The table is sorted on the p-value in ascending order, since it is the most important test in this study. That is because this value is a good way to find out the probability if it does follow a power law or not. The next parameter is Alpha, which is the slope of the hypothetical power law. Following that is X-min, which is the starting value from where the distribution can fit a power law. Finally, the number of vertices and their mean degree value are in the last two columns.

The p-value is a value derived from a statistical test, the Kolmogorov-Smirnov test. It indicates the probability of the degree distribution following a power law (Clauset et al., 2009). Even though a lot of empirical data looks like it follows a power law distribution, it is not always the case. If the p-value is larger than 0.1 it is probable, but not certain, that the data follows a power law.

It seems likely that the results can be grouped into two rather distinct categories, those with a p < 0.1 and those with p > 0.1. This means that approximately half of the cities’ street network degree distribution does not fit a power law, while the other half has a decent probability to do that. This finding is interesting since a statistical distribution can tell something about the growth process that has created it. If we identify what differs in the two categories according to section 1.3, there is one main factor that differs: top-down planning or governing during city growth, versus organic growth.

<table>
<thead>
<tr>
<th>City</th>
<th>P-value</th>
<th>Alpha</th>
<th>X-min</th>
<th>#Vertices</th>
<th>Mean</th>
<th>Growth process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brasilia</td>
<td>0,00</td>
<td>2,60</td>
<td>3</td>
<td>7646</td>
<td>3,566</td>
<td>Entirely planned from start</td>
</tr>
<tr>
<td>Paris</td>
<td>0,00</td>
<td>2,44</td>
<td>4</td>
<td>13043</td>
<td>4,822</td>
<td>Planned to a large extent</td>
</tr>
<tr>
<td>New York</td>
<td>0,01</td>
<td>2,32</td>
<td>6</td>
<td>3449</td>
<td>6,590</td>
<td>Entirely planned grid</td>
</tr>
<tr>
<td>Moscow</td>
<td>0,03</td>
<td>2,52</td>
<td>3</td>
<td>14471</td>
<td>4,354</td>
<td>Planned to express power</td>
</tr>
<tr>
<td>Beijing</td>
<td>0,11</td>
<td>2,49</td>
<td>4</td>
<td>4862</td>
<td>4,736</td>
<td>Planned</td>
</tr>
<tr>
<td>Tokyo</td>
<td>0,29</td>
<td>2,55</td>
<td>7</td>
<td>19007</td>
<td>4,934</td>
<td>Organically grown</td>
</tr>
<tr>
<td>London</td>
<td>0,39</td>
<td>2,73</td>
<td>6</td>
<td>16786</td>
<td>3,832</td>
<td>Organically grown</td>
</tr>
<tr>
<td>Damascus</td>
<td>0,40</td>
<td>3,09</td>
<td>8</td>
<td>6337</td>
<td>3,765</td>
<td>Organically grown on Roman grid</td>
</tr>
<tr>
<td>Venice</td>
<td>0,46</td>
<td>3,50</td>
<td>8</td>
<td>2145</td>
<td>3,425</td>
<td>Several cities organically grown together</td>
</tr>
<tr>
<td>Rio de Janeiro</td>
<td>0,88</td>
<td>3,13</td>
<td>9</td>
<td>8240</td>
<td>4,021</td>
<td>Many organically grown favelas</td>
</tr>
</tbody>
</table>

Table 2 - Results of the calculations on the cities
The cities with a p-value below 0.1 have all been subject to rigorous planning and structuring, even though the purpose, time and type of planning vary (Kostof & Tobias, 1991). The other cities that have a larger p-value are all to a varying extent what is called organic grown cities (Kostof & Tobias, 1991; Batty & Longley, 1994; Hillier, 1996), or cities with large areas of organic patterns. These so called organic cities are those where the city to a large extent has slowly grown over a long time and have not been not subject to any comprehensive planning effort. There is a city on the edge of the p-value limit, Beijing. The value means that it cannot be ruled out that it fits a power law, although it is just 0.01 above the limit. It is unclear why this is the case, but it would be surprising if all data could perfectly fit the dichotomy of way of growth.

The next parameter is alpha. It tells us the scaling factor in the distribution. Even though the differences are not as striking as for the p-values, they can also be divided into two categories with significant different mean. Alpha values are generally higher in the group of organic cities than the planned ones. The alpha values tell us that the organic cities have relatively fewer roads with high degree compared to the number of low degree roads. This might be explained by the process behind city evolution: in organic cities, the preferential attachment process results in that new roads strive to attach to the existing roads with high degree, while few new roads with high degree are built from the start. That means that the growth process in organic cities results in the evolution of the fine-grained background network, while the high degree foreground network is more stationary. In planned cities, a common measure is to create many high degree streets like highways, boulevards and main streets. This has various reasons, mainly political ones or ways to handle traffic. More high degree roads means more arterial roads that can handle larger amounts of traffic.

The x-min also seems to somewhat correlate with the division into organic versus planned cities and the alpha value. The reason behind this finding is unknown, but correlation with alpha values are often found (Gillespie, 2015). It can be interpreted that all cities might share a universal pattern for low degree streets up to around a degree value of ten. Since the slope of this part seems pretty flat, it fits a lower alpha better.

It seems that, based on these measures, whether the degree distribution fits a power law tells something about the level of planning in a city. This result can be explained by considering the city as a self-organized scale-free network (Barabasi & Albert, 1999). If a city is not subject of large scale planning, it tends to organize itself according to the principle of preferential attachment (Volchenkov & Blanchard, 2008) which is a kind of multiplicative growth (Batty & Longley, 1994) that results in a scale free network. That explanation is also in line with previous research (Jiang, 2007; Volchenkov & Blanchard, 2008). What the result in this study indicates, is that not all cities can be explained in this way; there seems to be a dividing line between planning and self-organization.
These results are interesting because they can give a good explanation to the earlier, sometimes contradictory, results from (Crucitti, P. et al., 2006; Porta, S. et al., 2006; Jiang, 2007; Volchenkov & Blanchard, 2008), where some results adhered to a power law while others did not. The steeper slope found in the organic cities can give a deeper explanation to the growth process behind them. Since there are mainly local bottom up forces that shape the city, relatively few primary high connected streets are built, because they require more central initiatives and large amount of resources. The higher proportion of the less connected streets is simply explained that they are necessary for the developing bottom up forces to connect to the street network. That makes sense since it is a more effective use of land (less proportion of roads) which is logical in the perspective that the forces behind bottom up-growth (often residential and firms) are acting economically.

6. CONCLUSIONS

This study has revealed similarities and differences in the degree distribution of the street network among cities with varying cultural, topographical, geographical or societal organizational circumstances. The factor that seems to explain the striking differences found in the degree distributions is the way of growth, organic bottom up or top-down planned. It seems that cities with an organic pattern likely follow a power law in their degree distribution. One the other hand, the extensively planned cities do not follow a power law.

These results can be useful in several ways. Firstly, they offer an explanation for the disparate results from other studies mentioned earlier, which have tried to find universal patterns in cities, often power law distributions. The answer to the question whether a universal pattern exists is: no, because it depends on the growth process of the city. Rather, it seems that there are at least two kinds of patterns.

Secondly, they elegantly verify the categorization and judgment that urban planning historians and theorists such as Kostof and Tobias have done on a qualitative basis, through visual analysis of the morphology. This opens up the possibility for urban planning historians, theorists and morphologists to support their work with quantitative analysis on a larger scale than the, usual qualitative, judgements allow.

Thirdly, for a long time there have been attempts to plan cities or neighbourhoods with an organic morphology. These attempts have often been unsuccessful or failed to produce the kind of urban fabric that was intended. The insights following this study might help these attempts, opening up a possibility to test various designs. The result can be used to see if they have the same properties as the organically grown cities that serve as models.

Although this study is too small to draw conclusive lessons, it provides clues and starting points for further studies. It also raises the question of whether there is some differentiated universal pattern in cities. It has shown that one measure of the street network can reveal such patterns and relations that seem to depend on the city’s history of growth and planning.
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#98

RELATING URBAN MORPHOLOGIES TO MOVEMENT POTENTIALS OVER TIME
A diachronic study with Space Syntax of Liverpool, UK

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ABSTRACT
In this paper we describe our observations of Liverpool's (UK) syntactical patterning relating to its urban network growth from 1850s to the present day. Liverpool’s rapid growth and transformation provides a compelling case study of network configurations as they relate to movement potentials over time. We argue that syntactical analysis of movement potentials provides a tool for evidencing urban historical socio-spatial patterning. Urban patterning might be shaped variously by historical factors such as socio-economic inequalities, labour divisions, ethnicities or religious denominations. We have attempted to demonstrate how movement potentials have persisted normatively along structural path-dependencies that underpin these patterns.

We based our study on samples of three prominent centralities of Princes Avenue, Scotland Road and Canning Place, across four periods: 1850s, 1890s, 1950s and contemporary. We prepared Depthmap data samples using an arrayed visualization format, which allowed us to make comparative observations of movement potentials as they converge and intersect across various urban scales. This has allowed us to generate ‘internal’ perspectives on configurations over time, to suggest some possible effects of city-scale morphologies on local spatial dynamics.

KEYWORDS
Urban morphology, movement potential, Liverpool, Space Syntax, urban history

1. INTRODUCTION
Britain’s rapid industrialization was driven by mass manufacturing across Lancashire coupled to Atlantic trade via the port of Liverpool (Hobsbawm, 1962, p.49-50). By the mid 19th Century, the city’s extensive wharf complex carried the world’s highest volume of cargo (Aughton, 2008, p.217). Much of Liverpool’s economic activity was focused along this complex (only a minor manufacturing area was centred around the Ropewalks area). The city’s high-density urban networks radiated outwards from the riverside, wherein some localized centralities supported trade and consumption. Massive inward migration from across the British Isles also led to highly segregated communities based on religion, nationality and work. Irish Catholics made up largely unskilled labour sub-groups around Scotland Road. Welsh Presbyterians made up semi-skilled labour groups around Princes Avenue. English and Scottish Protestants made up skilled labour and clerical groups also around Princes Avenue and in suburban areas (Pooley, 1977; Lawton, 1979). See Figure 1 for a map showing the main locations referred to in this paper.
By 1911, when construction of the landmark Royal Liver Building was completed, the port city had reached its peak of growth and innovation, followed by a decades-long process of general decline. The Depression of the 1930s led to one third of working-age men being out of work (Aughton, 2008, p.244), and wartime bombardment and displacement led to intensive damage to the city’s fabric. In the postwar years, road building, slum clearances and mass rehousing led to a precipitous decline in population within a severely post-industrial landscape (Cf. Sykes et al, 2013). High unemployment and social exclusions led to the major Toxteth Riots of 1981, which furthered the distress to Liverpool’s urban fabric. In spite of recent urban developments, Liverpool remains one of the most deprived cities in the UK measured by IMD, featuring extensive zones presenting high unemployment, high rates of chronic illness, low rates of educational attainment, and low longevity (LCC, 2015).

The urban history of Liverpool provides a compelling case study in rapid industrial transformation and accelerated decline. Tracing the distinctively ‘urban’ evolution of a city poses a range of epistemological dilemmas, which we have attempted to resolve to some extent in this paper. Firstly, do we deal with the city as an autonomous or as a complimentary entity within its wider spatio-temporal context (Jansen, 1996)? Secondly, how do we reflect the general ‘problem’ of urban space as, at once, the locus of everyday living and the site of normative (cultural and ideological) reproduction (Rodger and Sweet, 2008; Lefebvre, 1991, p.50; Hillier and Hanson, 1984, p.22)? Thirdly, how do we accommodate the paradox of the city as both a compressor of space-time, in terms of rates of flows and exchanges, and as an instrument for socio-spatial distancing, in terms of social differentiations expressed in spatial patterning (Dennis, 2008; Massey, 1994, p. 147), and relational complexity (Hillier, 2007, p. 67-68; O’Brien and Psarra, 2015)?

Space Syntax offers a method to address dualities in urban formation through its ‘configurative’ model of morphological generation, whereby generic spatial patterning relates dynamically to characteristic social practices (Hillier and Vaughan, 2007). This approach has been successfully applied to a range of ‘industrial age’ urban histories (for example, Psarra et al, 2013; Griffiths,
2009, 2017; Al-Sayed et al, 2009; Pinho and Oliviera, 2009; Vaughan, 2007; Vaughan and Penn, 2006; Medeiros et al, 2003). However, Hillier and Hanson's configurative theory, from which these analyses have extended, has been critiqued for its epistemological perspective of an 'external observer' of urban space (Griffiths, 2011). We argue that the configurative perspective should be that of the 'internal observer', whose situated space-time coordinates determine a localized (relativistic) modality for spatial description. The 'internal perspective' is pertinent to urban historical analysis when we conceive of how flow rates through urban networks in the past related to the capacities of their dominant mobilities (Urry, 2004). For example, the movement-scale paradigm of a predominantly pedestrian milieu offers affordances for spatial description that are qualitatively differentiated from those of an automotive milieu. Moreover, these local spatio-temporalities set in place basic components for the urban system's spatial evolution. As such, we cannot describe an urban history without considering the 'clocks' of its landscape (Ingold, 1993).

Urban historians are presented with a challenge in evidencing relativistic spatio-temporalities (Pooley, 2016). Pooley (2016) has reviewed, for example, a diverse set of historical materials relating to transportation-in-use within British conurbations. From the evidence available, it appears that most urban inhabitants from the mid 19th Century walked or took horse-drawn and, later, electric omnibuses. Suburban inhabitants in the early 20th Century depended on electrical omnibuses and, later, on personally driven automotive cars (that from the later 20th Century also introduced social inequalities of inclusion and accessibility).

Another approach to this challenge might be sourced from the Space Syntax notion of natural movement potential (Hillier and Iida, 2005), which encapsulates a method to recover probabilistic urban movements from the 'internal observer' perspective. Natural movement potentials (represented through Space Syntax measurements of Choice and Integration) may approximate the inter-relationships of these movement scales and network morphologies, as well as interactions between scales such as those between local through-movement and global to-movements – while recognizing that labels such as 'local' and 'global' are normative and negotiable over time. Space Syntax can provide the urban historian with 'potential' evidence that engages in new ways with traditional data sources; for example, in relating street networks bearing high Integration values to census data reflecting demographic segregation in those areas – as was typical of 19th-century Liverpool (Pooley, 1977; Lawton, 1979). In this paper, we mainly explore Space Syntax as a theory and a method for breathing new life into such sources, offering richer interpretative possibilities than conventional GIS visualization techniques (Griffiths, 2012, 2013; Vaughan and Penn, 2006).

2. DATASETS AND METHODS

In investigating Liverpool's historical urban network we sampled three major centralities converging around Princes Avenue in Toxteth to the city's south, Scotland Road in Everton to the north, and Canning Place in the city centre. The urban networks were modelled by tracing Ordnance Survey Ancient Roam tiles using QGIS. The tracings were exported to Depthmap for recalculation with angular segment normalized Choice and Integration measures (NACH and NAIN), based on metric radii of 200m, 400m, 800m, 2000m, 5000m and 'global n' scale respectively. We sampled from four historical periods: the 1850s marking the height of Liverpool's first wave of expansion; 1890s as the period approaching the city's economic zenith; the 1950s marking the city's network maximum; and the contemporary network subsequent to major remodeling and developments. In addition, we generated a Depthmap model (NACH and NAIN, R100, R250, R400, Rn) to reflect urban redevelopments to the city centre in the 1970s. This diachronic sampling constitutes one section of a broader project at University College London, 'Visualizing Community Inequalities' (supported by the Leverhulme Trust). The project seeks to describe contemporary community formations in relation to persistently 'imageable' urban forms, such as boundaries, interfaces and thresholds (Conroy-Dalton and Bafna, 2003; Lynch, 1971). To achieve this kind of observation, we generated Depthmap model arrays using an R programming environment (RStudio), to make comparative observations 'within the
eyespan’ (Tufte, 2006). This comparative method is reflected in our citing throughout text of the radial scales from which we made our observations (e.g. ‘NAIN 400’, ‘NACH 5000’ and so on). We provide an overview of the diachronic samples in Figures 2 and 3.

2.1 PRINCES AVENUE, SOUTH LIVERPOOL

Princes Avenue is a boulevard complex, built in the 1840s along an east-west axis over ancient parkland and gardens. The avenue connected the new metropolitan Princes Park to high-status residential areas. It was constructed as a dual carriageway that continues to play a major role in the urban formation of Liverpool’s Toxteth area (Figure 4). By the 1850s, several local plots had been developed with densified terraced housing, forming distinctive grid patterns. These sections presented overall low Choice, compared with that of the burgeoning city centre, and were separated functionally from the wider network by the foreground structures of Upper Parliament Street (NAIN R5000).

Figure 2 - An array of Depthmap models of Liverpool, UK, representing the syntactical evolution of urban regional Integration over four historical periods (NAIN Rn)

Figure 3 - An array of Depthmap models of Liverpool, UK, representing the syntactical evolution of urban regional Choice over four historical periods (NACH Rn)

Figure 4 - An array of Depthmap models of Liverpool’s Princes Avenue area (1890s map)
The land surrounding Princes Avenue had been urbanised with high-density terraced-housing street sections (and given characteristic nicknames; see Figure 1, points 10-13). Movement potentials within the local street sections were based on generally low-movement structures of short, straight street segments (NACH 400, 2000). These were connected at the perpendicular to moderate-movement segments, together bounded by street segments presenting high Choice at wider scales (NACH R400, R2000 and R5000).

Separate to the high-density grids, the interstitial ‘Granby Triangle’ was the location of ostensibly higher-status housing, along with a cluster of landmark Protestant, Orthodox and Jewish places of worship. Princes Avenue afforded these families improved accessibility to the city centre, to omnibus services, public parks, mercantile and cultural quarters (NAIN R800 and R2000). In contrast, movements of the Welsh Streets and Holy Land seem to remain orientated to the riverside industries (NACH and NAIN, R400 and R2000).

By the 1950s Liverpool had undergone a second-wave expansion based around low-density suburban and peripheral developments, inter-connected by a radial complex that included the Queens Drive ring road (opened around 1920) and the Mersey ‘Queensway’ Tunnel (opened 1934). Intensive wartime bombardment had led to several major disruptions to the urban fabric; nevertheless the Victorian urban network remained largely intact. The expansion of the network overall appears to have increased high Choice values along Princes Avenue, as well as among its adjacent street-section areas (NACH R800, R2000, R5000). The array of rectilinear segments now inter-connected the street sub-networks (NACH R200), with movement flowing along Princes Avenue and into to the urban-scale centrality along Upper Parliament Street (NACH R5000). Together these provided consolidated accessibility from all street sub-networks to the city centre (NAIN R400, R800, R2000, R5000), although accessibility from Princes Avenue to the newly expanded network was apparently more limited (NAIN R5000, Rn).

The 1950s also mark a pivotal moment in Liverpool’s economic and social decline. Granby’s prosperity lasted from the city’s economic zenith of the 1900s until the early 1960s. After this period Granby experienced a rise in crime, which led to the widespread installation of bollard arrays to prevent kerb-crawling (SNAP, 1972), which diminished Choice and Integration among the street network (NAIN and NACH R800, R2000).

This pattern of functional severance may have intensified a tendency towards spatial and demographic segregation, reflected in a concentration of non-white British populations within the Granby Triangle (HMSO, 1981). Relating to this, in 1981 a major riot broke out on Selbourne Street (an internally integrated segment within the Granby Triangle; NAIN R800), which led to the destruction or demolition of 70 buildings in the near vicinity. In the aftermath of these events, Liverpool City Council undertook the Urban Regeneration Strategy, to develop additional low-density housing close to the city centre.

Today, Princes Avenue presents high Integration from Liverpool’s southern periphery to urban centre (NAIN n). Strikingly, the southern carriageway of Princes Avenue (conveying traffic into the city centre), now presents low Choice (NACH R2000), compared to the generally high value of the 1950s. The avenue’s segment lying perpendicular to the Welsh Streets appears to be a weak attractor for the local network (NAIN R400), which is perhaps a dynamic feedback from extremely high rates of vacancy along these streets. Also striking in the vicinity are the persistently high Choice and Integration values along the north-south axis of Lodge Lane, representing an emergent local and city-scale centrality (NACH and NAIN, R400 and R5000).

2.2 SCOTLAND ROAD, NORTH LIVERPOOL

Scotland Road is a major conduit situated on a natural elevation along a north-south axis, connecting Liverpool’s urban centre to northern regional areas. It was developed as a highway in 1803, adjoined by an array of high-density terraced and court-yarded streets. Scotland Road (Figure 5) ran between distinctive areas of Vauxhall and Everton, which were associated with Protestant and Catholic migrants from within the British Isles.
Everton in the mid 19th Century featured a localised ‘ladder’ pattern of short streets that afforded overall good accessibility to the wider urban network (NAIN R₄₀₀, R₈₀₀, R₂₀₀₀). These street sections were inter-connected via functional ‘bridges’ that traversed local- and city-scale urban sub-networks (NACH and NAIN, R₄₀₀ and R₂₀₀₀), including economic centres of the mercantile quarter and riverside complexes.

The location of the North Hay Market, widely known as ‘Paddy’s Market’, formed a major centrality for surrounding streets and the wider urban network (NAIN R₄₀₀, R₂₀₀₀, R₅₀₀₀, Rₙ), (Figure 6). Highly significant in this dynamic was the perpendicular junction of Juvenal Street and St Anne Street, from where the market could be entered, forming a pivot of convergence for Liverpool’s network globally (NAIN Rₙ and NACH Rₙ). The affordances for economic and social mobility brought about by these encounters are perhaps reflected in the innovative public housing established at close-by Summer Seat and Eldon Grove (1911-12).

The contemporary map represents intensive redevelopment of the 1960s, including widespread demolition of the ‘ladder’ streets, and construction of radial roads and the Mersey ‘Kingsway’ Tunnel complex (opened 1971). This radial expansion integrated the urban peripheries but formed prominent boundaries between the northern districts and wider network (NAIN R₅₀₀₀, Rₙ), and localized lacunae in the urban fabric. The location of Juvenal Street is now, sadly, a barren pedestrian bridge over the subterranean tunnel approach, bearing only moderate prominence as an attractor and conduit at all scales (NAIN AND NACH, R₄₀₀, R₂₀₀₀, R₅₀₀₀ and Rₙ).

The sites of many of the ‘ladder’ streets have been redeveloped with low-density semi-enclosed complexes across north Liverpool. Together these form a loose cluster with overall low local Integration (NAIN R₄₀₀ and R₂₀₀₀), also demarcating a zone of among the highest multiple deprivations in the UK (ONS, 2015). The low-density housing complexes have led to poor connectivity among the north-south axes of Scotland Road and Great Homer Street, with only St Anne Street affording direct access between the roads (NAIN R₄₀₀ and R₂₀₀₀, NACH R₂₀₀₀). The overall poor connectivity between the north-south axes is perhaps suggestive of areas with weak local inter-connectivity and subject to movement from across the wider urban network.

Figure 5 - An array of Depthmap models of Liverpool’s Scotland Road area (18gos map)
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2.3. CANNING PLACE, CENTRAL LIVERPOOL

Canning Place is the site of among Liverpool’s earliest urban spatial structures and converges a historically persistent centrality at multiple network scales (Figure 7). From the 1850s, Canning Place formed a significant attractor within the city-wide network (NAIN R2000). At the local scale, Canning Place inter-connected the mercantile quarter around Dale Street, the cultural quarter around St George’s Hall (NAIN R400), and functionally integrated this sub-network with the Scotland Road axis via Whitechapel (NAIN R2000), and to regional routes (NAIN Rn).

The southern edge of Canning Place formed part of a boundary around the ‘maritime quarter’ sub-network, bisected diagonally by Paradise Street that traversed the ‘mercantile’ and ‘cultural’ quarters’ sub-networks (NAIN R2000 and R5000). As such, the place’s southern edge formed a powerful attractor and conduit for movement at all scales, converging along the city’s foreground network (NAIN and NACH, R400, R2000 and R5000). Benefitting from this major, multi-dimensional centrality, Canning Place was the location for Liverpool’s impressive Customs House.

Figure 6 - Depthmap array showing top quintile value ranges for NACH 400 and NAIN 5000, highlighting the ways in which local high Choice around Paddy’s Market may have coincided with a city-wide attractor.

Figure 7 - An array of Depthmap models of Liverpool’s Canning Place area (1890s map)
By the 1950s, after intensive bombardment, the Customs House had been demolished along with most of the surrounding buildings. This led to a general decrease in movement potentials around the site (NACH and NAIN, R2000). However, the southern edge of Canning Place, which formed an axis with Hanover Street, remained functionally resilient to the damage in the surrounding network. It continued to serve as a conduit from Strand Street to the newly established radial routes into the city's expanded suburbs (NACH R2000, R5000, Rn).

Canning Place's 1970s redevelopment involved a complex of municipal buildings and Strand Street's redevelopment as a multiple-lane highway (Figure 8). Significant to the sub-network's connectivity with the wider network, the major axis of Upper Frederick Street that connected Canning Place with residential areas to the city's south (ultimately including the Princes Avenue area), had been devastated by wartime bombardment, yet was partially restored in the 1970s redevelopment. This served to increase Choice within the Canning Place network (NACH R400). However, a major housing development initiated by the City Council in 1984 severed the junction of Upper Frederick Street and Paradise Street.

Cable Street and Thomas Street had provided, until the wartime period, city-wide attractors and conduits that linked South John Street and Paradise Street (NAIN and NACH R2000). Notably, these structures formed part of a prewar sub-network (observable from the 1890s, NAIN R400). Their 1970s successor was a pedestrian pathway of sorts, passing through a car park and bus terminal. In spite of this architectural disruption, this pathway maintained its movement potential as a local attractor (NAIN R400). This functional persistence possibly speaks to a spatial logic for movement that has formed from the foreground structure of the Great George Street/Berry Street axis (forming the city-centre’s western edge), and its functional connectivity, via Seel Street/College Lane, with the natural flow of Paradise Street.

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The area's redevelopment of 2004-2008 involved demolition of the 1970s architecture, and pedestrianization of local thoroughfares. The development restored the earlier prominence within the network of Canning Place's northern edge, now called Thomas Steers Way (NACH and NAIN, Rn), to provide pedestrian access to a new retail area. What is today called Canning Place is formed from its erstwhile southern edge, comprising a walkway and roadway for the main bus terminal. The roadway has maintained its historical prominence at local and city-wide scales (NAIN R400 and R2000). However, its walkway that was once the location of the Customs House forecourt has become functionally disconnected from movements among Liverpool's foreground network and southern neighbourhoods (NAIN R400 and R2000).
3. DISCUSSION

Our aim in using syntactic descriptions for making detailed diachronic observations of Liverpool’s urban development was to demonstrate how a ‘normative’ method for historical and spatial comparisons could reveal path-dependencies with the capability of underpinning urban images, including boundaries, thresholds, interfaces, gateways and bridges through which community identities are negotiated and controlled.

The Depthmap model arrays provided compelling observations of Princes Avenue’s function as a boundary and threshold between the sub-networks to which it was inter-connected. On the basis of this research one can propose how populations occupying Granby, the Dickens Streets and Welsh Streets in the mid 19th Century appeared to experience different orientations with respect to the wider network. Princes Avenue provided the major conduit for access to the metropolitan network, but with low inter-connectivity among the local networks. This suggests that Granby, the Dickens Streets and Welsh Streets where functionally separated and, we anticipate, socially segregated.

We discovered several examples of systemically confluent conduits and attractors that have, we argue, played various parts in community life at the different historical intervals we sampled. For example, Paddy’s Market in the mid 19th Century attracted localized movements, as we might expect from such a significant place in the urban landscape. The syntactical model also revealed how this local sub-network converged with through-movement structures at the wider city scale, possibly revealing its function as an interface between working-class communities to the north of the city and various populations from across the city. We also observed how the radial road developments of the late 20th Century formed structural boundaries between these local sub-networks and the wider network, also reflected in their experiences of slum clearance, mass relocation and de-densification.

A historical threshold pattern is also detectable along Scotland Road that, in the mid-to-late 19th Century and into the mid 20th Century, provided a conduit into the city, but functioned as the dividing line between different local sub-networks. This major road provided accessibility to sub-networks proximal to riverside industries, meaning the various populations occupying distinctive (and segregated) areas encountered each other along its segments. We observed how functional ‘bridges’ around Scotland Road traversed residential and industrial areas. Their street corners and local pubs were likely to have been significant gateways for economic and social brokering, not least given the casual availability of work. These spatially ‘trivial’ yet socially important street segments warrant further analysis.

We also discovered the resilience in movement potential of segments relating to the Canning Place sub-network. The northern and southern edges of the place have persisted as a significant interfaces between various sub-networks including, in the late 19th Century, those of the mercantile and cultural quarters and those of the socially mobile Princes Avenue quarters (though less so with regard to the lower working-class areas to the city’s north). We included an overview of structural interventions of the 1970s, which weakened the functionality of Canning Place as a conduit and attractor within the local and wider networks; its northern edge in particular became demoted as a city-wide centrality. We also observed how redevelopment in the 2000s restored the northern edge’s functionality within the local network, and promoted its southern edge within the wider network.

4. CONCLUSION

This study has offered a visualization method for making systematical observations of the historical growth of an urban street network that facilitates new forms of engagement with other sources of evidence and approaches to the study of urban history. Furthermore, we believe that it has produced evidence for the existence of normative ‘images’ of urban community formations in the historical street network. Further work using, for example, contemporary demographic data, journalistic accounts and individual testimonies, as well as greater statistical validation, is required to establish the credibility of this hypothesis.
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RELATING URBAN MORPHOLOGIES TO MOVEMENT POTENTIALS OVER TIME
A diachronic study with Space Syntax of Liverpool, UK


Rodger, R. and Sweet, R. (2008), ‘The changing nature of urban history’. In *History in Focus: The City*. Available at: <https://www.history.ac.uk/ihr/Focus/City/articles/sweet.html >


ABSTRACT

In this paper, Space Syntax methods of analysis have been applied to analyse the syntactic configuration of 28 high-risk streets in three Jordanian cities in order to explore the contribution of syntactic characteristics on accidents occurrence at these streets. The study incorporated Space Syntax - axial and segment analysis to produce a set of key syntactic measures including connectivity, integration, relative asymmetry, and choice. Syntactic measures were compared to traffic accidents data that were collected through the Central Traffic Department at Jordan. Statistical analyses were performed using three types of analysis; Correlations, One-Way ANOVA, and Regression. Statistical analysis showed that local measures Connectivity, Integration $R_3$, and real relative asymmetry $R_3$ were major syntactic properties that explain part of traffic accidents occurrence at high risk streets. The paper concludes that despite the differences in the street network density among the three cities, there is no significant difference in the syntactic characteristics of their high-risk streets. This study will help planners and designers to focus their efforts on improving streets where high rates of accidents are expected. Space Syntax provides a tool for assessing cities’ urban grid and develop transportation project when needed tools and resources are rare.

KEYWORDS

Space Syntax, Urban Grid, High Risk Streets, Traffic Volume, Jordan

1. INTRODUCTION

The growing traffic problems facing many urban areas today have resulted in a significant number of studies that seek to address the issue of traffic accidents. The Space Syntax (SS) is one approach that have been incorporated in transportation studies to investigate the influence of the urban configuration on patterns of pedestrian and vehicle flow throughout the city. Making it possible to predict the distribution of movement in the city’s streets, based solely on the street network and the nature of streets connections (Jayasinghe, Sano, & Nishiuchi, 2015; Lerman, Rofé, & Omer, 2014; Raford & Ragland, 2004). Predicting patterns of movement in the city helped in developing accident models to visualize the distribution of traffic accidents.
throughout the city and to define the locations of high level of risk (Greene-Roesel, Diogenes, & Ragland, 2007; Obeidat & Al-Hashimi, 2015).

This paper is an extension to previous researches that integrates Space Syntax theory with transportation studies by investigating how the streets network in the city as seen from a syntactic perspective corresponds to traffic accidents occurrence at high risk streets. The study involves twenty-eight streets chosen from three Jordanian cities; Irbid, Madaba, and Ramtha. Streets under-investigation are classified as high-risk or hazardous streets by the department of traffic at Jordan. It is important to note here that classifying a street as a high-risk differs from one country to another, depending on the rate of fatalities or injuries.

In this paper, we assume that there is an association between the way high-risk streets are articulated in the urban grids and the potential incidence of traffic accidents found in each street. The research offers specific recommendations for areas that are considered high at risk or are associated with high rate of traffic accidents.

1.1. INSIGHTS FROM TRANSPORTATION STUDIES

A number of publications approach the issue of accident prevention through the physical design of urban streets. For example, Dumbaugh and Rae (2009) in “Safe Urban Form” reviewed some of the basic design ideas to increase safety on streets. The main principles include (1) increasing the sight distance and (2) designing streets with limited access. Increasing the sight distance incorporates widening and straightening streets to enhance drivers’ ability to see the hazard before physically encountering it. While, the limited access principle minimizes the number of intersections along the street in order to decrease the opportunities of encountering vehicles and pedestrians with each other. Some researchers sought to examine the validity of these principles on their studies. For example, Choueiri, Lamm, Kloeckner, and Mailaender (1994) found a negative relationship between available sight distance and accident risk. The accident rate decreases with the increase of sight distance of more than 750 m (2,450 ft). In addition, studies showed that an increase in streets width leads to a decrease in accident frequency (Abdel-Aty & Radwan, 2000; Watanabe & Nakamura, 2016).

At the urban scale, the view of the relationship between the urban form and accidents occurrence is widely confirmed by many studies. For instance, Marks (1957) found that neighbourhoods with through traffic and gridiron patterns witnessed higher number of crashes than the limited access communities. Rifaat, Tay, Perez, and Barros (2009) found that contemporary patterns with loops and cul-de-sac were associated with lower crash rates than gridiron patterns. Lovegrove and Sun (2010) also found that irregular patterns were safer than grid, and cul-de-sac patterns. These studies draw attention to the notion that streets organization within the urban form can either limit or regulate the potential encounters among different vehicles or pedestrians. For example, gridiron patterns might increase the number of traffic causing more accidents to happen unlike limited access patterns.

The effect of traffic volumes on traffic safety has been examined by Scholars, but they reported different conclusions. Some studies reported that streets and intersections with high volumes were found to be associated with increased crash incidence (Abdel-Aty & Radwan, 2000), while others found them to be associated with significantly fewer crashes (Obeidat & Al-Hashimi, 2015). In general, all of these studies concluded that traffic volume is an important indicator for risk.

During the last few years, space syntax has been applied in transportation studies to model the distribution of movements in the city’s streets and to predict traffic flows. The results show a clear correlation between the dispersal of movements and the streets’ degree of spatial integration (Greene-Roesel et al., 2007; Lerman et al., 2014; Raford & Ragland, 2004). Data generated by space syntax analysis were employed to model pedestrian accidents and to define high risk streets (Obeidat & Al-Hashimi, 2015; Raford & Ragland, 2004). However, what is missing is a genuine understanding of the relationship between streets’ spatial characteristics with accidents occurrence focusing on high risk locations. More precisely, we need to know how streets with high rate of accidents are placed in relationship to the configurative structure of
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the city. Using space syntax analysis, we can identify underlying spatial conditions of the high-risk streets whether they are segregated streets (that are visually broken up with urban grids with less accessibility and connections to all other streets in a city) or integrated ones. We can provide an evidence as to how the streets’ spatial characteristics could be held responsible of causing a high rate level of accidents.

2. RESEARCH METHODOLOGY

The analysis of three cities; Irbid, Madaba, and Ramtha have been incorporated in this study to investigate the spatial characteristics of their high-risk streets. The cities ranged between high to low-street network density as shown in Figure (1) below. Traffic accidents data for each city were collected through the Central Traffic Department at Jordan. In 2015, a total of 1750 traffic accidents were reported in these three cities. 54.2% of these accidents involved pedestrians. In addition, accidents in these cities have resulted in 93 fatalities (15.3 % of total fatalities in Jordan) and 3068 injuries (19.0 % of total injuries in Jordan) (Central Traffic Department, 2015). Due to the growing accidents problem, the Jordanian Central Traffic Department worked to define accidents’ locations or streets that pose a high risk to their users at different cities in Jordan. More than 557 streets that classified between low, medium, to high risk were identified from this investigation (Central Traffic Department, 2015). Figure (1) shows the locations of high risk streets on the map of each city that is incorporated in our study.

A separate analysis was conducted on the street grid for each city using UCL-DepthMap software to derive the syntactic values (including connectivity, integration, relative asymmetry, and choice) for the 28 high-risk streets. The study then used a correlation analysis to explain the relationship between the various syntactic parameters and the number of accidents occurring on each street.

Figure 1 - Locations of Different High Risk Streets at Each City Map

2.1. SPACE SYNTAX ANALYSIS

Space Syntax’ Axial and Segment analyses were performed in this study. Axial lines represent the longest and fewest possible lines of sight that cover all routes of movement in the city (Hillier, 2007). While, segment lines are axial lines that are broken down into smaller segments at each intersection. The relationship between the lines and their connections provides a number of spatial indices of street grids that describe movement flows through streets. Indices include integration, connectivity, choice, and relative asymmetry. (1) Integration indicates the number of directional changes from one line in a network to all of the other lines. This measure can offer a description of the level of accessibility of a high-risk street to other streets in the
(2) Connectivity reflects the number of axial lines directly intersecting with a specific line. This measure can describe the number of neighbouring streets directly intersecting with a high-risk street. (3) Choice measures the likelihood that a certain line is most used for traveling between different spaces in a city. This measure can describe whether a high-risk street allows traffic from all other routes to pass through it to all other spaces in the entire system. And (4) Relative asymmetry measures (RA and RRA) are standardized and inverse measurements of integration, which calculate the deepness of an axial line from a certain line without considering the number of lines in the system. These measures are helpful in defining integration measures without considering the size of the cities in comparison.

Of the measures produced by UCL Depthmap, the following axial-based variables were picked as independent variables in the study: Table 1 shows the syntactic analysis for the three cities.

- **Axial-based variables (topological measures):**
  - Integration (global and local with a radius of 3)
  - Connectivity
  - Choice

- **Segment-based variables (angular measures):**
  - Integration
  - Connectivity
  - Choice
URBAN GRID AND TRAFFIC SAFETY:
Using space syntax as an assessment tool

3. RESULTS

Using IBM SPSS 22 (SPSS, 2013), statistical analyses were performed using three types of analysis; Correlation, One-Way ANOVA and Regression. Correlation analysis were used to describe the relationship between the number of pedestrian accidents and the various syntactical properties. Analysis of variance (One-Way ANOVA) was used to describe the variance among the three cities in relation to different variables included in the study. And Regression analysis was used to identify whether the relationship between the dependent and independent variables as a cause-effect relation.

Table 1 - The Syntactic Analysis of The Three Cities.

<table>
<thead>
<tr>
<th>City</th>
<th>Connectivity</th>
<th>Local Integration R3</th>
<th>Choice</th>
<th>RRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irbid City</td>
<td>C.A: 4.62</td>
<td>HRA: 11.55</td>
<td></td>
<td>C.A: 2.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 361725</td>
<td>HRA: 1203989</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 1.9</td>
<td>HRA: 2.73</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 75952</td>
<td>HRA: 253654</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 0.886</td>
<td>HRA: 0.68</td>
</tr>
<tr>
<td>Madaba City</td>
<td>C.A: 3.62</td>
<td>HRA: 9.99</td>
<td></td>
<td>C.A: 1.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 94724</td>
<td>HRA: 547235</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 1.104</td>
<td>HRA: 0.813</td>
</tr>
<tr>
<td>Ramtha City</td>
<td>C.A: 3.83</td>
<td>HRA: 12.2</td>
<td></td>
<td>C.A: 1.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 75952</td>
<td>HRA: 253654</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C.A: 0.886</td>
<td>HRA: 0.68</td>
</tr>
</tbody>
</table>
3.1 ANALYSIS OF ALL STREETS TAKEN TOGETHER

Spearman correlational analysis is conducted here to understand the effects of syntactical properties on accidents’ occurrence through the analysis of all streets taken together. The correlation coefficients presented in Table (2) show that there are insignificant and weak correlations among axial global integration and choice values and the total number of pedestrian accidents. However, the correlation coefficients show significant relationships among local axial variable: connectivity, local integration R₃, and Real Relative Asymmetry values and the number of accidents at high risk streets.

The correlation coefficients show that axial connectivity (R₃) had moderate negative correlation with the total number of pedestrian accidents which yields a Spearman r equal to -0.462 (P value = 0.013). Axial connectivity values can provide an explanation of 17 percent of the total variation in pedestrian accidents at high risk streets, where high connectivity values induce lower number of accidents. The correlation coefficients show that the local Integration (R₃) displays moderate negative correlation with the total number of pedestrian accidents which yields a Spearman r equal -0.524 (P value = 0.004). Local integration (R₃) can explain 17.8 percent of the total variation in pedestrian accidents, high integrated streets induce lower number of accidents. The results display moderate positive correlation between real relative asymmetry R₃ measure and accidents number, which yields a Spearman r equal 0.529 (P value = 0.004). This indicates that streets with low values of real relative asymmetry or low deepness at local level in streets’ system would probably witness low number of accidents.

The statistical analysis did not show significant correlations between segment based variables, connectivity and integration, and the number of accidents. However, the analysis showed a significant correlation between the number of accidents and angular choice value. The correlation is moderate and positive that yields a Spearman r equal 0.418 (P value = 0.027). This indicates that streets with high choice values that allow more through traffic would probably witness high number of accidents.

<table>
<thead>
<tr>
<th>Syntactical variables</th>
<th>Spearman r</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connectivity</td>
<td>-.462*</td>
<td>.013</td>
</tr>
<tr>
<td>Global Integration Rₙ</td>
<td>-.169</td>
<td>.390</td>
</tr>
<tr>
<td>Local Integration R₃</td>
<td>-.524**</td>
<td>.004</td>
</tr>
<tr>
<td>Choice</td>
<td>.105</td>
<td>.596</td>
</tr>
<tr>
<td>Relative Asymmetry R₃</td>
<td>.366</td>
<td>.056</td>
</tr>
<tr>
<td>Real Relative Asymmetry R₃</td>
<td>.529**</td>
<td>.004</td>
</tr>
<tr>
<td>Segment Analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connectivity</td>
<td>-.228</td>
<td>.244</td>
</tr>
<tr>
<td>Integration</td>
<td>.178</td>
<td>.365</td>
</tr>
<tr>
<td>Choice</td>
<td>.418*</td>
<td>.027</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

Table 2 - Variables and Summary of Correlations
3.2 ANALYSIS BASED ON THE CITY

Tukey test after ANOVA is conducted here to compare the effects of syntactical properties on accidents’ occurrence among the three cities.

As presented in the Table (3) below, the analysis of variance generally show insignificant differences among high-risk streets in the three cities (Irbid, Madaba, and Ramtha) in terms of the number of accidents and syntactical properties. This finding indicates a similarity in high risk streets’ syntactical properties even though they are located in cities that differ in street network density (high, medium, or low).

However, the analysis of variance show significant different among the three cities in relation to their axial and segments’ global integration values Rn. High-risk streets in Ramtha (a city with low density) are more globally connected to other streets in the city unlike high streets in Irbid and Madaba city. The results also showed that the three cities differ in their angular choice values. This indicates that high risk streets in Irbid city allow more through traffic than other cities.

<table>
<thead>
<tr>
<th>Syntactical variables</th>
<th>F</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accidents</td>
<td>.144</td>
<td>.866</td>
</tr>
<tr>
<td>Connectivity</td>
<td>.777</td>
<td>.471</td>
</tr>
<tr>
<td>Global Integration Rn</td>
<td>5.780</td>
<td>.009</td>
</tr>
<tr>
<td>Local Integration R3</td>
<td>1.613</td>
<td>.219</td>
</tr>
<tr>
<td>Choice</td>
<td>.890</td>
<td>.423</td>
</tr>
<tr>
<td>Relative Asymmetry R3</td>
<td>1.383</td>
<td>.269</td>
</tr>
<tr>
<td>Real Relative Asymmetry R3</td>
<td>1.442</td>
<td>.255</td>
</tr>
<tr>
<td>Connectivity</td>
<td>2.443</td>
<td>.107</td>
</tr>
<tr>
<td>Integration</td>
<td>69.090</td>
<td>.000</td>
</tr>
<tr>
<td>Choice</td>
<td>3.886</td>
<td>.034</td>
</tr>
</tbody>
</table>

Table 3 - Cities' Streets Comparison and Summary of ANOVA Analysis

3.3 REGRESSION ANALYSIS

Regression analysis is performed here to identify whether there is a causation between the syntactical measures and traffic accidents. A stepwise regression analysis was implemented. Based on this analysis, a model that predicts traffic accidents at high risk roads was developed. The model indicated that axial connectivity is an important variable in explaining traffic accidents at high risk roads. Connectivity values can predict 15.9 percent of total variation in traffic accidents (P value = 0.035).
4. CONCLUSIONS

This paper incorporates Space Syntax analysis to investigate how the streets network in the city as seen from a syntactic perspective corresponds to traffic accidents occurrence at high risk streets in that city. Our results show that syntactical measures did explain part of accidents occurrence at high-risk streets. In the study, axial local measures (Connectivity, Integration R3, and real relative asymmetry R3) were major syntactic properties that explain traffic accidents occurrence at high risk streets. The findings indicate that a street with low number of connections with surroundings routes makes it more vulnerable to accidents due to the decrease of traffic volume at the street level. This finding is consistent with previous studies findings that consider traffic volumes as important indicator for accidents occurrence. When the number of traffic passing the street goes down, accidents frequency increases. Jacobsen (2003) explained that a motorist in this situation is more likely to collide with a person walking or other vehicles when there is less traffic in the street (Jacobsen, 2003).

Previous research indicates that urban areas with high network density appear to be safer than the lower-density environments (Marshall & Garrick, 2011). Our study did not find any significant differences in the syntactical properties among high risk streets that are located in different cities (with different street network density) and accident occurrence on these streets. The regression study found that the local measure of connectivity is a good predictor in explaining 15.9% of accident occurrence in high-risk streets.

We hope this study will help planner and designers to focus planning and infrastructure efforts on improving streets where a large amount of accidents takes place. Furthermore, the results can be used to develop a policy that seeks to improve traffic safety where the lowest traffic movement rates are expected. Using the space syntax approach in analysing street properties would allow planners to take more a proactive role in assessing cities’ street network and develop transportation planning projects in Jordan and other countries.
REFERENCES


WHY ANGULAR CENTRALITIES ARE MORE SUITABLE FOR SPACE SYNTAX MODELING?

ABSTRACT

The street network’s angular properties were found more suitable than metric properties for capturing the observed pedestrian and vehicle movement flows in space syntax modeling. Some studies relate this state to the underlying street network structure that create the potential for movement across the network. The aim of this paper is to clarify why the angular structure of the network has superiority over the metric structure. The investigation entailed analysis of street network’ centralities and movement flows obtained through agent-based simulations conducted for two cities that differ in the pattern and size of street network. The findings indicate that the superiority of the angular structure can be explained by two structural properties: (i) a multi-scale correlation between to-movement and through-movement potentials (centrality measures) of the same distance type; and (ii) an overlap between movement potentials of different distance types across scales of the network. These structural properties create coherent and dominant angular foreground structures that fit movement flows in both study cities.

KEYWORDS

Movement potentials, Distance type, Scale, Space syntax

1. INTRODUCTION

The spatial distribution of movement in street networks is an essential component for a city’s functioning and dynamics. Understanding the effects that shape the movement of pedestrians and vehicles is crucial for predicting traffic flow and enhancing efficiency, safety, sustainability and livability in urban environments. Previous studies have explained movement flows in urban street networks by factors such as the street network’s morphological and physical aspects, land-use patterns, residential and employment densities, as well as access to public transit (e.g., Desyllas et al., 2003; Hillier and Iida, 2005; Omer et al., 2015). However, at its core, the spatial distribution of movement flows is related to two types of effects: the street network’s movement potentials and the individual’s spatial behavior. These effects are explained as follows: the network’s structure creates movement potentials (i.e. ‘network effects’) whereas
individuals, by choosing the shortest routes in the network, determine how these potentials will be utilized (e.g. Hillier, 2012).

Although route choice is affected by various factors which can differ from the shortest routes (e.g. Manley, 2015; Turner, 2009), the common guiding assumption behind most research is that people try to minimize trip length, based on their distance perception. When calculating the shortest routes to their destinations from within the network, people use three basic types of distance (Hillier and Iida, 2005): Metric distance, topological distance (the number of changes of direction that have to be made on a route) and angular distance (the sum of the angles characterizing the direction changes made on route). Hence, several types of movement potentials – metric, topological and angular – embedded within the network, which are rooted in the individuals’ spatial behavior.

Studies that examined the correlation of movement flows with topological, angular and metric street network centrality properties (i.e. movement potentials) in different urban areas (e.g. Hillier and Iida, 2005; Hillier, 2009; Jayasinghe et al., 2015; Turner, 2007; Xia, 2013) have shown that the correlations with angular street networks’ centrality properties tend to be higher than the correlations with topological properties but mainly higher than the correlations with metric properties. The relevance of the street network’s topological-angular properties for capturing the observed pedestrian and vehicle movement flows in the network was supported by many other studies (e.g. Hillier, 2009; Jiang, 2009; Jiang et al., 2008). In addition, empirical evidence has been obtained regarding the correspondence between the street network’s topological-angular properties and retail land use patterns in various cities (e.g. Omer and Goldblatt, 2015; Scoppa & Peponis, 2015; Vaughan et al., 2010), features that are strongly related to patterns of movement flows in urban networks.

Some researchers (e.g., Hillier and Iida, 2005; Hillier, 2012; Penn, 2001) have argued that movement flows in urban networks appear to be related mainly to the dominance of the topological and the angular distances in individuals’ spatial behavior. Other studies have nonetheless suggested that the underlying street network structure can also determine movement flows, irrespective of individuals’ spatial behavior (Jiang and Jia, 2011; Omer and Jiang, 2015). Further indications of this ‘independence’ of aggregate movement flows from individuals’ spatial behavior is the lack of variability found in the predictability of movement flows despite significant differences in human travel patterns (Song et al., 2010). However, it is yet to be ascertained how the underlying street network structure contributes to some degree of ‘independence’ of movement flows in the network. In other words, there is no comprehensive answer available for how the ‘network effect’ works and why the topological-angular structure of the network has superiority over the metric structure.

Several street networks’ structural properties are related to movement flow. The first structural property of the network is the emergent multi-scale centrality in the network what called by Hillier (2009; 2016) ‘pervasive centrality’. According to this view multi-scale pattern of linked centres arises in cities through a well-defined process of self-organization, based on the relationship between the street network structure and movement at all scales. This process by which the pattern of ‘pervasive centrality’ evolves in cities is essentially occurs at all scales in the foreground network (the main streets/ longer lines), though it interacts with the structure of the background network (small streets/shorter lines). Hence, the foreground and background structures are both components of a locally and globally efficient system of inter-related to-movement and through-movement potentials (Hillier, 2016). This intricate pattern of movements at all scales is related to the angular structure of the network. Moreover, the conjunction between to-movement and through-movement was also found to be significant property of the angular structure (Vaughan et al., 2010; Hillier et al., 2012).

The second structural property is a structural overlap that exists between street network’s movement potential of different distance types. Although previous studies have referred to the relevance of overlapping between movement paths at different scales for enhancing efficient and sustainable movement in cities (Hiller, 2009; Salingaros, 2005), no attention is given to overlapping between distance types. We argue that the examination of overlap between
street network’s movement potentials of different distance types, with an explicit reference to individuals’ spatial behavior, might also explain the observed corresponding between the angular foreground structure and movement flow in the network.

The aim of this paper is to compare between the angular and metric street network structures by focusing on the structural properties discussed above: (i) an emergent multi-scale correspondence between to-movement and through-movement potentials (centrality measures) of the same distance type; and (ii) an overlap between movement potentials of different distance types across scales of the network.

To achieve this aim, the analysis was concentrated on angular and metric street network structures (centrality measures) and movement flows obtained through agent-based simulations conducted for two Israeli cities.

In the following section we describe the cities studied, the measurement methods employed, and the data, together with the agent-based model constructed to simulate the various types of distance movement. The research findings and conclusions appear in the third and final section.

2. DATASETS AND METHODS

2.1. SELECTING STUDY CITIES, DATA, AND ANALYSIS

The two cities chosen for the study – Kfar Saba and Beer Sheva – differ in their street patterns, land-use distributions and size (Figure 1), features that enable the examination of consistencies in the structural properties. In addition, both cities are locationally independent, with no directly adjoining cities and hence no need to confront any ‘edge effect,’ which can critically impact on the results of a space syntax analysis (Gil, 2015). Kfar Saba, founded in 1912, developed mainly through continuous urban growth. The city is characterized by a predominantly orthogonal street pattern, with retail activities concentrated in its center. In contrast, Beer Sheva, a relatively young city, developed according to a comprehensive city plan after establishment of the State of Israel in 1948. The city is characterized by hierarchical street patterns and its residential neighborhoods were designed according to the ‘neighborhood unit’ model (Omer & Goldblatt, 2015). The differences between such cities may be reflected in movement flows (Marshall, 2005; Jiang and Liu, 2009).

Data for the cities’ street networks (updated for 2012), as GIS layers, were obtained from GISrael (a geographic information database for Israel offered by the company “Mapa”). Data on non-residential buildings were obtained from the Survey of Israel - MAPI (the official Israeli government agency for Mapping, Geodesy, Cadastre and Geoinformatics).
2.2. MEASUREMENT OF STREET-NETWORK MOVEMENT POTENTIALS

The space syntax approach allows description of the street network’s movement potentials with centrality measures that are generally computed on the basis of either axial or segment maps (Hillier and lida, 2005). Axial maps are constructed with the smallest set of straight axial (visual) lines covering the urban street network. Axial maps can subsequently be transformed into connectivity graphs, in which the axial lines and the intersections between lines appear as the graph’s nodes and links, respectively. The centrality of each axial line within the network is then computed based on graph connectivity attributes. Segment maps are constructed by means of the line segments connecting junctions of axial lines, a feature that facilitates configurational analysis on a finer scale than do axial lines. Segment analysis also allows consideration of angular (least-angle distance) and metric distance (Hillier and lida, 2005) as well as variability in the distribution of traffic volumes.

Two types of centrality measures are used in the space syntax approach for describing a street network’s movement potential – Integration and Choice – measures that correspond with the graph theory-based measures closeness and betweenness, respectively. Closeness represents a given street segment’s accessibility within the network (i.e. its to-movement potential) while betweenness represents the extent to which a segment functions as an intermediate location within the network (i.e. its through-movement potential). The betweenness measure actually counts the number of times a segment lies on the shortest path between all pairs of origins and destinations in the network. The segment-based measures used in this paper are identical to those defined by Hillier and Iida (2005, pp. 481-483):

\[
\text{Closeness} (S_i) = \frac{n - 1}{\sum_{k=1}^{n} d(S_i, S_k)}
\]

where \(d\) is the shortest (topological, angular or metric) distance from a given street segment \(S_i\) to every other street segment \(S_k\) in the segment map. Betweenness is defined as:

\[
\text{Betweenness} (S_i) = \sum_{j=1}^{n} \sum_{k=1}^{n} \frac{P_{jik}}{P_{jk}}
\]

where \(P_{jik}\) denotes the shortest paths from \(j\) to \(k\), and \(P_{jik}\) the shortest paths from \(j\) to \(k\) that pass through street segment \(S_i\).

Each centrality measure was computed at several metric radii – 250, 500, 750, 1000, 1250, 1500, 1750, 2000, 2500, 3000, 4000, 5000 m – and over the entire urban area (radius n), as used in the space syntax research (Hillier, 2009). Construction of the segment maps and computing space syntax measures was completed with Depthmap software (version 10.14, UCL), and visualized with ESRI’s ArcMap (ver. 10.3) GIS software.

2.3. AGENT-BASED SIMULATION

The simulation model we employed was designed with the NetLogo (ver.5.3.1) environment (Wilensky, 1999). Segment maps of Kfar Saba and Beer Sheva were transformed into NetLogo environments from the ArcGIS software (ver. 10.3). Two types of agents were defined according to how they would choose the shortest path – metric and angular – between origin-destination pairs. The shortest metric path was computed with the Dijkstra algorithm (Dijkstra 1959) within the NetLogo framework, while the shortest angular distance was obtained by computing cumulative angular change between origin and destination.

The probability of a street segment being chosen as a destination is directly proportional to its accessibility in the network (i.e. closeness value values):

\[
\text{Closeness}_{\text{Acc}} (S_i) = \frac{\text{Closeness} (S_i)}{\sum_{k=1}^{n} \text{Closeness} (S_k)}
\]
where \( n \) is the total number of streets segments; and \( S_i \) is the closeness value of a given street segment \((S_i)\) as computed by formula (1). The measure \( \text{Closeness}_{\text{Acc}} \) is computed for each of the two distance types –angular, and metric. Agents were programmed to use their respective destinations according to the computed closeness measures, e.g. metric agents selected movement according to accessibility as computed by the metric closeness formula.

During initialization of each simulation run, agents’ movement origins (starting points) are randomly created. Once they reach their first destination, they choose their second destination according to the \( \text{Closeness}_{\text{Acc}} \) measure, and so forth. Agents are programmed to choose the shortest path according their type. For each simulation run of 36k iterations, we assigned 15 agents to each of the two types (a total of 45 agents). For each simulation run, the aggregate movement flows of each of the two agent types was computed at the segment level by the gate counts method (e.g. Jiang and Jia, 2011).

3. RESULTS

The geographic distributions of the betweenness and closeness centralities by distance type, together with the simulated movement flows of each agent type (agents selecting the shortest angular or metric route), are shown for Beer Sheva and Kfar Saba in Figures 2. The maps show that the to-movement (closeness) and through-movement (betweenness) potentials of the angular distance type tend to be similar relative to those of the metric distance. It can be also seen that in both cites the metric to-movement potential (closeness) tends to be especially concentrated close to each city’s geographical center while the metric through-movement potential is distributed relatively more equally throughout the entire network. In addition, while the angular through-movement potential is concentrated along a few streets, particularly along the long lines, the metric through-movement potential is distributed more equally along a relatively greater variety of line lengths.

![Figure 2 - Spatial distribution of centrality measures (movement potentials) at the segment level in Kfar Saba (a, c, e, g) and Beer Sheva (b, d, f, h).](image-url)
This differential correspondence between the to-movement and through-movement potentials of the angular and metric structure, as demonstrated graphically by the correlations obtained between the centrality measures of each distance type across scale, is presented in Figure 3. It can be seen that the overlap between the to-movement and through-movement potentials of angular distance is relatively higher comparing to metric distance, and especially at the local scales. In addition, the distance types also differ in the change of overlap between the movement potentials across scales.

Figure 3 - The correlations between betweenness and closeness centrality measures (level of correspondence between to-movement and through-movement potentials) of the same distance type at different metric radii.

3.1 MULTI-SCALE CENTRALITY IN THE NETWORK

To identify the spatial patterns of the correspondence between the to-movement and through-movement potentials in the angular and metric structures of the street networks a detailed analysis was conducted at the segment level for both cities. The conjunction between the movement potentials across scale was examined using a k-means clustering algorithm of MATLAB (ver. 9.1). K-means clustering is an iterative, data-partitioning algorithm that assigns n observations to exactly one of k clusters defined by centroids, where k is chosen before the algorithm starts.

The results of the analysis (figure 4) enable to make a distinction between the foreground and background structures of the street network. It can be seen clearly that in both cities the angular foreground structure reveals more clearly emergent multi-scale centrality reflected in intensifying of the correspondence between the to-movement and through-movement potentials from the local to global scales. The segments of the angular foreground structure are also creating more coherent spatial structure than the metric foreground structure. In other word, to-movement and through-movement potentials are integrated spatially well in the angular foreground structure. It can be also seen that the spatial patterns of the angular segment clusters that increase across scale tend to reach higher values than the metric segment clusters, especially at the larger scales.
WHY ANGULAR CENTRALITIES ARE MORE SUITABLE FOR SPACE SYNTAX MODELING?

Figure 4 - Multi-scale centrality in the metric and angular network at the segment level in Kfar Saba and Beer Sheva (a, c and b, d, respectively). The relative amount of segments in each cluster appears in brackets. The total street segments in Kfar Saba and Beer Sheva are 2,923 and 9,178, respectively. To normalize the Betweenness and Integration centrality measures, the values of each measure for each segment was divided by the sum of all segments. Then, the combined centrality measure (Betweenness \* Integration) was computed by multiplying the normalized centrality measures’ values of each street segment.
3.2 STRUCTURAL OVERLAP BETWEEN DISTANCE TYPES IN THE NETWORK

The simulated movement flows of metric and angular agents are presented in Figure 5. It can be seen clearly that the angular movement flows are concentrated relatively on the main lines of the networks in both cities. The shortest routes of all types of agents tend to pass through the long axial lines (with minimal angularity) but, unlike the angular agents’ shortest routes, the metric agents’ shortest routes are also distributed among relatively shorter axial lines (mainly in the city’s geographical center).

Since the movement potentials of metric and angular distance types overlap to some degree, actual movement according to a given distance type may simultaneously utilize the movement potential of other distance types (i.e. metric and angular shortest paths for a given origin-destination pair might overlap to some degree). The agent-based simulation was implemented in order to examine this mutual utilization of movement potentials by different distance types.

In order to clarify the mutual utilization found between the movement potentials of the distance types, the correlations of the simulated metric and angular aggregate flows with the metric and angular centrality measures across scales (metric radii) were examined (see Figure 6). The graphs in Figure 6a show how metric agents utilize metric and angular movement potentials, while the graphs in Figure 6b show how angular agents utilize the same movement potentials. The results clearly indicate the presence of systematic overlapping and mutual utilization between the two types of movement potentials. That is, each agent type also utilizes the movement potential of the other distance type. However, this mutual utilization of movement potentials is, in both cities, asymmetric: metric agents tend to utilize the angular movement potential more than angular agents utilize the metric movement potential, especially concerning the to-movement potential (closeness centrality).
The correlations of the aggregate flows are clearly higher with angular closeness than with the metric closeness at all scales, no matter which distance type — metric or angular — the agents use. This mutual utilization also exists with respect to the through-movement (Betweeness) potential, implying that utilization of a given shortest route may involve the concurrent utilization of another type of shortest route. However, as a result of the different levels of overlap between the movement flow types across scales (see also figure 3), the asymmetric utilization of to-movement potentials is more prominent at local scales, with the asymmetrical utilization of through-movement potentials more prominent at higher scales. These tendencies are quite consistent for both cities.

The asymmetric utilization is reflected well when the analysis is concentrated on the angular structure, as illustrated in figure 7: metric agents tend to use the angular through-movement potential (figure 7 b, d) more than do angular agents use the metric potential (figure 7 a, c). In other words, metric shortest routes pass over angular shortest routes more than metric shortest routes pass over angular shortest routes. Hence, as a result of structural relations between distance types within the street network, the angular movement potentials of the network are utilized more often than are the metric movement potentials.
4. CONCLUSIONS

The study findings reveal systematic differences between the angular and metric structures of the study cities’ street networks. First, the angular foreground structure exhibits more coherent spatial pattern of emergent multi-scale correspondence of the to-movement and through-movement potentials than the metric foreground structure. Second, an asymmetric utilization between the movement potentials of different distance types is found: angular movement potentials are more-intensely utilized than metric movement potentials, particularly those of the foreground structure of the network. In addition, as the simulation results show, these street network’s structural properties contribute to a certain degree of independent of the aggregate movement flows on individuals’ spatial behavior. The movement flows of different agent types subsequently tend correlate with the angular structure of the street network. These tendencies are consistent with the network’s pattern and size of the study cites – Beer Sheva and Kfar Saba. Overall, this study sheds light on how structural properties within the network create coherent and dominant angular structure that fit movement flows. However, further work is needed based on real-world variables that are related to the relationship between street networks’ structural properties and movement flows, such as land-use patterns.
WHY ANGULAR CENTRALITIES ARE MORE SUITABLE FOR SPACE SYNTAX MODELING?

REFERENCES


ACCESSIBILITY OF SPATIAL NETWORKS:
Using ArcGIS Network Analyst and Space Syntax to Investigate Accessibility to Urban Facilities

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ABSTRACT
Accessibility is a critical objective in the field of planning, particularly for urban facilities such as education and health services. Among many models and techniques that calculate accessibility, this study focuses on network analyst tool of ArcGIS and space syntax methodology. In the network analysis of ArcGIS, it is possible to calculate service areas for individual urban facilities within given distance/time limits. Space syntax measures on the other hand, help to understand the overall accessibility dynamics of the network. This study aims to associate space syntax based accessibility evaluation and service area measures of ArcGIS in the city of Mersin, Turkey.

Mersin is one of the most populated cities of Turkey with more than 1.5 million people. It has a sloping topography which has affected the development of both the road structure and the settlement structure of the city. Apart from the urban centre, there are villages with rural character in mountainous parts of the city that do not have proper access to most urban facilities. Health and education services are of vital importance and access to these facilities is a must for both urban and rural settlements. Therefore, accessibility of these particular facilities within the Mersin Municipal Area is the main focus of this study.

In 2015, the Greater Municipality of Mersin initiated the preparation of an urban development plan for Mersin. Urban development plans usually consider accessibility as a means to organize general transportation flows but not as a network issue that would affect individual accessibility of facilities. Therefore, it is important to understand the direction of development in cities before planning them. In order to comprehend development trends and needs of urban facilities, two types of accessibility analyses were carried out in Mersin. Firstly, health and education facilities were assessed using network analysis toolset of ArcGIS, separately for hospitals, school of medicine and small scale health facilities for health services; elementary schools, middle schools and high schools for education services. Secondly, segment based space syntax analysis was executed, in which integration measures were inspected.

Comparison and integrated evaluation of results of these two types of analyses are believed to serve to an improved comprehension of the morphological spirit of Mersin. Further analyses on such issues would play a crucial role in planning.

KEYWORDS
Space syntax, network accessibility, polycentric development, Mersin
1. INTRODUCTION

Accessibility to facilities, particularly regarding access time, is one of the critical indicators of quality of life, although alone it would not be adequate to ensure a high quality of life (Cooper & Roadman, 1994; Doi, Kii, & Nakanishi, 2008; Hewko, Smoyer-Tomic, & Hodgson, 2002).

Urban social facilities can be listed as health, educational, socio-cultural, administrative, religious, recreational, and sports facilities. Doi et al. (2008) refers to disadvantages of certain social groups such as children, elderly people and the disabled, in terms of scope of mobility. In planning, it is generally assumed that all social groups have equally high mobility (Doi et al., 2008). Accessibility of these groups to urban facilities must not be equated with other groups and should be considered separately. Among urban facilities, health and education services widely address children, teenagers and people in need of health care, which places them in disadvantaged groups. Therefore, accessibility of these facilities in certain time constraints is more fundamental.

Overall accessibility schema of a city depends highly on the operation of road networks (Liu & Yu, 2012). Space syntax is a method that analyses geometries of urban networks and provides mathematical explanations to evaluate accessibility (Hillier & Hanson, 1984). Traffic jam and urban sprawl are regarded as the most critical results of road networks, which are the common problems of large cities. To cure these problems, urban structure needs to be understood better (Roth, Kang, Batty, & Barthélemy, 2011).

Theories of urban structure, which are developed in order to understand and explain development trends of cities independent of planning, suggest three main theories (Keleş, 2010).

Concentric growth theory proposes that cities develop in concentric rings that are land-use zones. The centre is not only geometrically but also functionally the heart of the city with commercial and business functions. Series of concentric circles are defined as central business, transition zone, working class residents, middle and higher income residents, suburban zone. This theory is criticized for it underestimates the complex structure of cities (Keleş, 2010). Complex spatial structures of modern cities are far from their historical concentric characters (Roth et al., 2011).

Sector theory depends on the thought that land-use zones are separated from city centre through peripheries like “slices”. Geometric centre is again occupied with business and commerce and residential areas are zoned according to different social classes. Main criticism about this theory is the way social classes are simplified. Besides, dynamics and localized systems of the 21st century are ignored (Keleş, 2010).

Polycentric growth theory claims that urban growth follows a multiple nuclei model. Size of the city affects the number of centres (Keleş, 2010). Common structure in industrial cities is the “monocentric” urban model, but modern cities are more complicated and they have a tendency to develop as polycentric (Legras & Cavailhes, 2016; Roth et al., 2011).

Polycentric urban development is a topic mainly in the field of geography and economics (Arribas-Bel & Sanz-Gracia, 2014; Burger, van der Knaap, & Wall, 2013; Yue, Liu, & Fan, 2010). One of the most effective qualities of this type of urban structure is that economic activity clusters in several centres. Although this type of polycentric structure is more than 100 years old, the term hasn’t been quantitatively defined, yet (Roth et al., 2011).

In a monocentric structure, on the other hand, all economic activity and development pressure is concentrated on a single centre. In fact, agglomeration of activities in the CBD reduces costs of communication, access to information and access to material (Sasaki, 1990). However, overconcentration of economic activities on specific geographies and underutilisation of resources in other geographies creates an uneven development (Burger et al., 2013). Besides, a study that evaluates communication and commercial costs confirms that polycentric agglomeration performs better than monocentric city, under specific circumstances (Legras & Cavailhes, 2016).
In order to relieve the development pressure from city centres, business decentralization happens as a natural and mostly unplanned process. Low prices and possibility for larger parcels in the urban periphery attracts firms, leading to decentralization of businesses and triggering a development that is no longer monocentric (Sasaki, 1990). According to Yue (2010) decentralization is the main reason that evoked polycentric urban spatial structure. In the same way, Burgess et al. (2013) suggests that the reason behind polycentric growth policies was to ensure the balanced distribution of economic activities (Burger et al., 2013).

Different levels of commercial and industrial activity that can be observed in different parts of the city generate the hierarchy of urban structure, which indicates a polycentric model (Roth et al., 2011). This uncontrolled decentralization process is very similar to principles of the new economic geography that insists on models that are in general equilibrium and in which spatial structures emerge from the invisible hand process (Krugman, 1998). Sasaki (1990) refers to this unplanned polycentric growth as non-monocentric.

Analysing accessibility is a reliable way to explore and assess the morphological structure of cities and to identify sub-centres in polycentric cities (Martinez Sanchez-Mateos, Sanz, Francés, & Trapero, 2014). This study analyses network accessibility of Mersin to assess its morphological organization and its tendency towards a polycentric development.

Accessibility of urban facilities has two main components; road network that provides access to facilities and location. The reason that this study underlines polycentric structure relies on the fact that these agglomeration sub-centres are also centres of population agglomeration. Therefore, most of the services are provided from these centres to less central settlements. Hewko et al. (2002) states that spatial accessibility is generally an evaluation of relations between residential areas and existing facilities, rather than assessing locations for possible facilities. In this paper, the aim is to investigate the possibility of utilising two different accessibility models together, both to examine the morphological organization of Mersin, and to evaluate the location of urban facilities with regards to their accessibility in order to develop guidelines on location of facilities.

Within this aim, network analyst tool of ArcGIS and space syntax methodology have been utilised. In the network analyst of ArcGIS, it is possible to calculate service areas for individual urban facilities within given distance/time limits. This method has been used to evaluate spatial accessibility of existing facilities in Mersin with regards to the amount of population that can receive services in definite time constraints. This way, it would be possible to define deprived regions according to specified time limits.

Space syntax measures, on the other hand, help to understand the overall accessibility dynamics of the network. In this study, space syntax local and global integration measures have been analysed to understand the morphological character and to evaluate polycentric tendency of Mersin.

2. CASE AREA

Mersin is one of the most populated cities of Turkey located in the south, enclosed by Taurus Mountains on the north and the Mediterranean Sea on the south (Figure 1). It has the second largest port in Turkey, which enables sea transportation to all the countries that has a coast on the Mediterranean and the Middle East. Convenience of sea, air and land transportation gives Mersin a strategic importance in its region and attracts industrial investment.

Mersin and its surrounding region have hosted many civilizations; in chronological order Hittites, Phrygians, Assyrians, Persians, Macedonians, Romans, Byzantines and Ottomans have ruled in the region. Mersin has become a province of the Turkish Republic in 1924. According to the latest census of 2013, Mersin has a population of approximately 1,700,000, 22% of which lives in village settlements.

Mersin has a complicated planning history. Most of the previous plans have covered only the city centre and close environments, until 2007, when the 1/100,000 scaled environmental plan
was approved. In 2008, another development plan (1/25,000) was approved, however was cancelled by the upper court. This process is followed by two regional plans in 1/100,000 scale in 2011 and 2013. These plans were not prepared specifically for Mersin; they included other cities since they were aiming regional development (Promer, 2015). In 2015, the Greater Municipality of Mersin initiated the preparation of a 1/50,000 scaled urban development plan for Mersin.

Due to Taurus Mountains, especially northern parts of the city have a sloping topography and both the road structure and the settlement structure of the city has evolved in line with these limitations. Topography of Mersin displays a pattern that draws “branch-like” traces of high elevation that are perpendicular to the sea. This pattern causes the road network to have a similar structure that is mainly in south-north direction. This road structure leaves gaps in east-west direction, which is the main reason behind poor accessibility. In most parts, roads draw zigzags in order to climb the steep topography. Apart from the urban centre, there are villages with a rural character in the mountainous parts of the city that do not have proper access to most urban facilities. Since access to health and education services are of vital importance for both urban and rural settlements, accessibility of these facilities within the Mersin Municipal Area is the main focus in this study.

Figure 1 - Location of Mersin in Turkey

3. METHODOLOGY

In order to understand the morphological structure of Mersin, two types of analyses have been carried out. First, accessibility to education and health services has been analysed through “Network Analyst” of ArcGIS software. For this set of analysis, “calculating service area” tool has been utilised. Accessibility analysis have been done separately for hospitals, school of medicine and small scale health facilities for health services; elementary schools, middle schools and high schools for education services. Second, segment based space syntax analysis were done, in which integration measures were inspected using DepthmapX (Varoudis, 2012).

Road-centre lines have been used for both types of analysis. The main road is an interprovincial highway starting from Mersin and reaching East Anatolian and South-East Anatolian towns. This highway has limited access from central road network. In ArcGIS, road-centre lines map has been revised to represent the connections accurately. In Depthmap, same revision to road-centre lines have been made using “unlink” tool to leave only the valid connections.

Calculating service area tool works with a road network that has time-cost data, which is calculated through segment length and average speed on the road. The tool creates a polygon data showing the areas within the given reach limits. For calculating service areas in Mersin, traffic flow data obtained from General Directorate of Highways has been used to get average values for different road types.
Calculated time limits are 5, 10 and 20 minutes for education services; and 10, 20 and 30 minutes for health services.

4. ANALYSES

4.1 NETWORK ACCESSIBILITY

In Turkey, elementary and middle school levels are regarded as “primary education” which is compulsory for all children in the 6-14 age group and is provided by the state free of charge. Regulations for Making Spatial Plans sets the maximum reach distance for educational services as 500m for elementary schools, 1000m for middle schools and 2500m for high schools; 500m for small scale health services. In Mersin, the city centre is more probable to comply with these regulations, however the rural parts of the city are far from standards. Taurus Mountains, which are within the city borders, enclose the city from north, lying in the east-west direction. The mountainous topography has critical effects on the road structure.

4.1.1 NETWORK ACCESSIBILITY OF EDUCATION FACILITIES

Although elementary schools are expected to be in 500m distance according to law, in this study, reach values are set in driving times, because 500m reach distances would not give a meaningful picture. Admitting that the actual schema is far from legislative standards, the values used for accessibility to educational services were 5, 10 and 20 minutes.

There are 454 elementary schools in the Mersin Municipal Area, most of which are located closer to central areas. Accessibility map for elementary schools shows that 280,000 ha area is covered in 5 minutes, 530,000 ha area is covered in 10 minutes and 790,000 ha area is covered in 20 minutes of driving distance (Figure 2). These figures appear as inadequate when the total area of Mersin Municipal area is considered: 1,625,000 ha. However, as mentioned before, most parts of the Municipal area is mountainous and settlements are sparsely located. Therefore, the number and population of the settlements that are within these catchment areas are investigated. Total number of settlements covered by this 5 min. reach distance is 398 out of 803. There is a population of 210,000 that does not have access to an elementary school within 5 minutes. When 10 minutes driving time is analysed, there is still 130,000 people out of reach of elementary schools and this number is 100,000 people when driving time is accepted as 20 minutes (Table 1).

![Figure 2 - Network Accessibility of Elementary Schools](image)
Number of middle schools within the Mersin Municipal Area is 332. Regulations indicate that the standard reach distance for middle schools is 1000m. Nevertheless, the same accessibility problems apply to middle schools, as in elementary schools. Analysis of middle school accessibility in 5, 10 and 20 minutes reach distances show that the catchment area in 5 minutes driving distance is 195,000 ha covering 343 settlements. In 10 minutes, 415,000 ha and 475 settlements are covered, and in 20 minutes, 720,000 ha is covered serving to 603 settlements (Figure 3). Number of settlements that cannot reach to a middle school in 20 minutes is 200 with a population of 116,000 (Table 1).

Number of high schools in Mersin Municipal Area is 142. Location of high schools and thus the reach extents concentrate on central areas such as Erdemli, Silifke, Mut, Gülner, Anamur, Tarsus and Mersin City Centre. Tarsus and Mersin City Centre appear as a single core in all of the analysis, as well as in the road network. This is also apparent in the analysis of high school accessibility, since high school location is usually one of the indicators of sub-centre location.

Regulations do not constrain the reach standard for high schools in walking distances; maximum distance is 2500m. As mentioned before, average speed values for different types of roads have been calculated using the traffic flow data from General Directorate of Highways. Average speed for central road network has been taken as 40km/h, which is low mainly because of poor road conditions. With this average speed, it is possible to reach 2500 meters in less than 4 minutes.

5, 10 and 20 minutes reach distances have been taken as break values for the analysis of high school accessibility. Analysis shows that total area covered in 5 min. driving distance is 60,000 ha serving to 28 settlements with a 1,300,000 population (Figure 4). Total number of settlements that do not have access to a high school in 5 minutes is 775 with a population of 370,000. According to this analysis, around 400 settlements and more than 200,000 people cannot reach a high school in 20 minutes of driving distance (Table 1).
4.1.2 NETWORK ACCESSIBILITY OF HEALTH FACILITIES

Network accessibility has been analysed separately for hospitals, school of medicine and small scaled health facilities for health services. Calculated time limits are 10, 20 and 30 minutes for all types of health services.

In Mersin, there is one university hospital that belongs to the Faculty of Medicine at the University of Mersin. It is located in the city centre, therefore even in the longest range (30 min) its access distance cannot reach to rural parts of Mersin. The area covered by the access distance of the University Hospital is 6,000 ha in 10 minutes, 30,000 ha in 20 minutes and 66,000 ha in 30 minutes (Figure 5). There are only 200 settlements in total that have access to the University Hospital in half an hour. However, since it is located in densely populated areas, approximately 1,200,000 people are within its reach distance (Table 2).
There are 17 hospitals within the Mersin Municipal Area distributed around central areas. Their total catchment area covers 95,000 ha in 10 minutes, 260,000 ha in 20 minutes and 420,000 ha in 30 minutes (Figure 6). As their locations are central, their catchment areas correspond to a high amount of population, despite the low number of facilities. Almost 90% of the population can reach a hospital in 30 minutes (Table 2).

Nevertheless, the number of small scaled health facilities is much higher but their spatial distribution seems to be favouring central areas. There are 224 small scaled health facilities composed of dispensaries, dental health centres, polyclinics, medical centres, family health centres and other small scaled health care units. Total catchment area of these health facilities in 10 minutes is 445,000 ha, in 20 minutes 830,000 ha and in 30 minutes, 900,000 ha (Figure 7). The catchment area of health facilities in 30 minutes cover most of the settlements however there are still over 80,000 people who do not have access to any type of health facility in 30 minutes (Table 2).
The distribution schemas of health services and their access distances support that, when it comes to access, location of facilities is much more important than the number of facilities.

Table 2 - Settlements that cannot access educational services within given time limits

<table>
<thead>
<tr>
<th></th>
<th>10 min. reach distance</th>
<th>20 min. reach distance</th>
<th>30 min. reach distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Health Facilities</td>
<td>311</td>
<td>153,882</td>
<td>155</td>
</tr>
<tr>
<td>Hospitals</td>
<td>557</td>
<td>469,729</td>
<td>413</td>
</tr>
<tr>
<td>University Hospital</td>
<td>741</td>
<td>1,123,625</td>
<td>686</td>
</tr>
</tbody>
</table>

4.1.3 SPATIAL ANALYSES
For spatial analyses, road centre lines map of Mersin Municipal Area has been used. Segment based space syntax analysis have been carried out to calculate local and global measures of integration using DepthmapX (Varoudis, 2012).

The most dominant road in Mersin is an interprovincial highway connecting Mersin to East and South-East Anatolian towns. Connections of the interprovincial highway to central road network are provided through access roads, linked on specific junctions. In order to represent these connections accurately, revisions to road-centre lines have been made using "unlink" tool in Depthmap.

Road network and settlement structure of Mersin has developed greatly in line with topographical limitations. Road density is much higher in the central areas, which are close to the sea. Tarsus is located on the eastern side of the city and is one of the most important centres in Mersin. It is almost as large as the city centre and in time, also as a consequence of its proximity to the city centre, strong road connections have developed between these two parts of the city. On the western side of the city, another large centre, Silifke is located. Silifke was a separate province until 1930s when it was administratively linked to Mersin. As both settlements developed and spatially expanded, now Silifke and Mersin City Centre also have strong connections. As the city is bordered with Mediterranean Sea on the south and Taurus Mountains on the north, development in east-west axis would be inevitable. Linking with two main centres accelerated this development, thus creating a linear hub.
This linear structure is evident in global integration analysis (Figure 8). There is a linear integration core continuing along the sea in east-west direction, displaying high values between Tarsus and Silifke. It is interesting to see that, Silifke actually has more highly integrated lines than Mersin City Centre. These lines are connected to the city centre through coastal road that also has high values.

In local integration analyses, 800m, 1600m, 3200m and 8000m radii are used. The central areas that create the linear integration core in global analyses, appear as separate centres in local analyses. Mersin City Centre and Tarsus are the most prominent and largest local centres in all of the local analyses. In addition, Silifke and Mut are displayed as local centres in 800m and 1600m (Figure 9).

Mersin Municipal Area has developed in a polycentric urban structure clearly due to geographical constraints. As accessibility analyses of urban facilities suggested, it is crucial to understand polycentric structure for a desirable urban development. Location of urban facilities are much more essential compared to number of facilities, to provide accessibility from different parts of the city. Central areas of the urban structure must be determined with regards to their potential and connection with the main centre. Space syntax local integration analyses provide valuable information to understand this structure.
5. RESULTS AND DISCUSSION

Main objective of this study was to investigate the possibility of utilising the network analyst of ArcGIS and space syntax methodology together to develop guidelines on determining the location strategies of facilities.

Using the network analyst of ArcGIS, spatial accessibility of existing education and health facilities in Mersin has been evaluated with regards to the amount of population that can receive services in definite time constraints. Even though access distances to schools and basic health services are defined by law as 500m, 1000m and 2500m, the general layout of the city reveals how unrealistic these distances would be. Therefore, in this study, access distances have been calculated in driving minutes.

In Mersin Municipal Area, there are 454 elementary schools, but still a population around 200,000 people are out of the service area of any elementary school in a 5 min driving distance. Elementary school children cannot be expected to take long distances to access their schools. Particularly, settlements located on the mountainous parts have a more problematic access. It is very justifiable that in every settlement unit, there needs to be at least one elementary school. For middle school and high school accessibility, there are respectively 115,000 and 200,000 people without service within 20min of driving, which suggests the need for additional educational facilities. Notwithstanding, number and location of these new facilities should follow a strategy of balanced distribution to cover all possible settlement areas.

The most striking result of this study has been achieved by comparing service areas of hospitals and small scaled health facilities. Total number of small scaled health facilities in Mersin Municipal Area is 224; hospitals is 17. Both of these facilities have been analysed using the same time limits. Results demonstrate that number of people that are in the service area of these facilities are not relevant with the number of facilities. Hospitals are in 30min access distance for 90% of the population, in which case we would expect 224 facilities to cover the entire population of Mersin Municipal Area. On the contrary, there are still over 80,000 people that cannot reach any type of health services in half an hour. In this case, either location of small health facilities is considerably imbalanced or location of hospitals is perfectly balanced. In any case, the need for additional education and health facilities is evident, although the bigger concern is obviously location strategy.

Space syntax measures on the other hand, have helped to understand the overall accessibility dynamics of the network. Syntactic analyses verify that Mersin Municipal Area has a polycentric structure, which is actually a result of its morphological formation. Evolution of the city has incorporated unification of settlements, and then enlargement of these settlements has created a dynamic whole. Still, these settlements preserve their independent character creating a polycentric city structure. Space syntax local integration analyses provided a visual and numerical presentation of these local centres, which are also consistent with the populations.

According to the analytic report (Promer, 2015), there is no data showing a significant difference among village settlements in terms of income. However, the topographical differences seem to have a great impact on the socio-economic structure. Areas that are up to 100m of elevation from sea level are where most of the urban settlements concentrate and where there is agricultural production. Mersin City Centre as well as Erdemli, Silifke, Anamur and Tarsus are located in this first zone. This zone harbours around 85% of the population of Mersin. Areas between 100m and 500m of elevation are identified as transition zones from urban to rural character. The area is divided by valleys and rivers, and is occupied with both forests and agricultural land (Promer, 2015). Mut is the biggest central settlement in this zone which is also one of the local centres defined by space syntax analysis. Areas between 500m and 1300m are characterized by forests, heathland or rocky lands. Another central settlement, Gülünar is located in this zone, which is the most elevated central settlement in Mersin. There are also some highland settlements where horticulture production is common. Areas over 1300m of elevation are mainly mountainous with very few settlements. These areas harbour 1% of the entire population of Mersin (Promer, 2015). This socio-economic structure is rather relevant with the accessibility schema provided by spatial analysis, since road network is more problematic in elevated areas, which are also areas with high slope.
The mentioned central settlements are also centres of district jurisdictions. In Mersin, there are 13 district jurisdictions, 4 of which have merged in time in the main centre of the city and are referred to as “Mersin City Centre”. Erdemli, Silifke, Anamur, Tarsus, Mut and Gulnar are of the central settlements which emerge in local integration analysis. On the other hand, there are 3 more district centres that have not appeared in local integration analysis, which are Bozyazi, Aydincik and Camliyayla. Therefore, it would not be accurate to assume that all district centres have a central character. The local centres specified in local integration analysis are not only areas where road surface is denser but also areas with higher accessibility.

In order to develop a location strategy for facility planning, the road network should be examined and local centres which are part of the polycentric structure should be identified, so that these centres could also be considered as centres for facility services. In this way, the population that would receive service in definite time constraints can be used to calculate capacity requirements for facilities. Furthermore, spatial analysis with lower radii could be used to define centres of a lower-level for planning locations of small-scale facilities. In this framework, elementary schools can be planned for each settlement, while middle schools can be located in second-level centres and high schools can be placed in first-level centres. Similarly, small-scale health facilities can be planned for each settlement, while health centres can be situated in second-level centres and hospitals can be located in first-level centres. Local integration analysis could be used to identify locations and levels of centres, while ArcGIS network service area function could be used to define the access areas of planned facilities and calculate the capacity requirements for the population within those areas.

In conclusion, both types of analyses have provided valuable information for planning the Mersin Municipal Area. Network analyses have displayed the service areas of analysed facilities and the population they are serving. Syntactic analyses showed the powerful integrity of the city in global analysis, while indicating sub-centres of its polycentric structure in local analyses. Analyses also confirmed that planning for urban facilities is not simply an arrangement of adequate number of facilities, but a strategy. Findings of this study are believed to serve to a better understanding of urban structures.

ACKNOWLEDGEMENT

Data for location of urban facilities, location of settlements, settlement populations and road centre-lines used in this study is from “Provincial Environmental Plan and Urban Area Research - Analytic Studies” initiated by the Greater Municipality of Mersin and conducted by the planning firm Promer in September, 2015.
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INTEGRATION IS NOT WALKABILITY
The limits of axial topological analysis at neighbourhood scale

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ABSTRACT
Spatial syntax analysis has become an influential method of analysing street networks as spaces of pedestrian movement. While significant correlations have been found between pedestrian flows and axial topological models, these models are inconsistent in the way urban morphologies are represented and measured. Meanwhile, in the fields of health, transport and urban design research, correlations have been found between walking and a range of urban morphological attributes that topological models ignore. This paper shows that while space syntax analysis has become increasingly sophisticated over the past decades, substantial limitations persist.

Focusing on the limits of the theory in its own substantive field, it is shown that the abstraction of the street to its axial line poses three fundamental problems. First, it eliminates the street section and thus does not recognise that the social logic of space is also transversal across the street. Second, it ignores permeability as a key morphological attribute linked to walkability at neighbourhood scale. Third, it transposes smooth urban conditions into striated measurable models that iron-out ambiguities, eliminating conditions of liminality, porosity and complexity. Yet all these dimensions have been recognised as key attributes of urban intensity at street level. In conclusion it is argued that while axial integration may be useful in studying larger urban networks to capture particular morphogenetic tendencies, it can be misleading as a measure of walkable access at neighbourhood scale.

KEYWORDS
Walkability, urban morphology, spatial syntax, topological analysis

1. INTRODUCTION
Spatial syntax analysis has become an influential method of analysing street networks as spaces of pedestrian movement (Hillier and Hanson, 1984; Hillier, 1996; Hillier and Vaughan, 2007). At urban scale it is based on an axial model of the street network corresponding to ‘lines of sight’. The ‘topological’ or ‘syntactic’ properties of this model are then measured using specifically developed software and represented through colour maps. Over the decades many such measures have been developed, the most common being integration and choice (Al-Sayed et al., 2014). The main testing ground for these methods has been London and other European cities with irregular street networks. These methods have been shown to be problematic in planned grid networks such as Manhattan (Ratti, 2004) and modernist morphologies as in southern Stockholm (Sayyar and Marcus, 2013). In response new syntactic models and measures have been added, including ‘segment analysis’ where the axial lines are divided into segments at each intersection. Measures have also diversified beyond axial topological to angular and metric as well as combinations of these (Al-Sayed et al., 2014). Thus while again and again significant correlations have been found between pedestrian flows and space syntax
models, these models vary in the way urban morphologies are represented and measured. Even within the same study, Hillier and Iida (2005) found that pedestrian flows in four central London neighbourhoods variously correlated with topological or angular models combined with integration or choice measures, with turn radii ranging from 12 to 102. There has been however only limited exploration as to why some models work better for some morphologies or scales and not for others (Berghauser Pont and Marcus, 2015). While space syntax models have become increasingly sophisticated, substantial limitations persist.

The broad critique of spatial syntax theory so far has been focused on reductionism and spatial determinism. Reductionism includes the reduction of spatial practice to movement, human interaction to bodily presence and urban space to its syntactic dimensions (Netto, 2016). Thus the social importance of urban squares and parks (Whyte, 1980; Sennett, 1992), the role of social networks in virtual space (Castells, 2009) and the role of orientation signs and landmarks (Lynch, 1960; Venturi et al., 1977) are disregarded. Furthermore, the broad body of research examining the relation between walking and urban spatial structure within the fields of health, transport and urban design research has linked walkability to a much broader range of attributes, including footpath quality, permeability, proximity to attractors and density (Lin and Moudon, 2010; Moudon et al., 2006; Porta and Renne, 2005; Frank et al., 2006; Cervero and Kockelman, 1997; Maghelal and Capp, 2011; Forsyth et al., 2008; Forsyth and Southworth, 2008). The critique of spatial determinism is focused on Hillier’s (1996: 169-170) key argument that more integrated areas tend to lead to higher densities, and higher densities tend to produce more functional diversity, which then leads to the emergence of urban buzz or urbanity. The high importance attributed to movement networks and the ‘movement economy’ is congruent with the work of other key urban theorist. For example Cerdá defined cities as ‘points along the universal economy of ways’ (Soria y Puig, 1999: : 103-115), and the capacity of the urban fabric to allow easy movement was one of four preconditions of vitality for Jacobs (1961). What is different in spatial syntax theory however, is the a-priory primary role attributed to street network configurations ahead of other morphological dimensions and various social practices (Holyoak, 1996; Soja, 2001).

Further to such broad critique, this paper focuses on what Netto (2016) calls the ‘limits of the theory in its own substantive field’, that is the limits of space syntax theory and its analysis methods as tools for understanding access networks and pedestrian movement. First the paper discusses the problems of dismissing the role the micro-morphologies of street sections have in mediating sociality. Then it shows that axial topological analysis is misleading as a measure of walkability at neighbourhood scale. Finally, it exposes the limitations of reducing geometry to algebra in the study of urban morphologies.

2. THE SOCIAL LOGIC OF STREET SECTIONS

The primary space syntax technique of axial analysis is a topological approach that abstracts street width and length to a node in a graph model (Fig.1). Here the conventional graph representation of streets connected by intersections is inverted: the streets become nodes and the intersections become the links (Hillier and Hanson, 1984). While the conventional graph model suits vehicular transport analysis where the focus is on intersections as traffic nodes and streets are seen as connections between nodes, space syntax focuses on streets as social nodes, while intersections are connections between these nodes (Marshall, 2005: 108-109). This inversion is assumed to be consistent with pedestrian behaviour where the streets are the main social spaces of interaction, origin and destination of trips, while the intersections are primarily links between them (Hillier and Hanson, 1984).
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In this process of abstracting the street section to its axis, the micro-morphology of the street section, including its width, public-private interfaces and footpaths are ignored (Fig.2). Yet it is well established that sociality in public space strongly relates to micro-morphological elements, including public-private interfaces, footpaths, seating opportunities and climate protection (Gehl, 1987; Gehl, 2010; Whyte, 1980; Gruen, 1965).

This reduction of the street section to its axis also means that the connectivity between the two sides of the street is not considered. Yet the morphology of the street section has been long recognised as of key importance for the social life of the street. Thus Cerdá recognised that while widening streets increases their longitudinal transport capacity, at the same time it reduces the transversal connectivity between buildings on opposite sides. He observed that the transversal connection was crucial to sociability in the neighbourhood, and was negatively affected by large street width (Soria y Puig, 1999: 194-196). The relation between axial vehicular traffic and transversal connectivity has been also explored by Appleyard (1981). His survey of residents of three streets in San Francisco showed that social relations across the street were strongly reduced where vehicular flows were greater. Similarly, in retail streets transversal connectivity enables synergies between the two sides of the street that tend to emerge in pedestrian malls where walking from one side of the street to the other is easy.

3. INTEGRATION, PERMEABILITY AND WALKABILITY
One of the most common criticisms of axial space syntax analysis is that it generally discounts physical distances, assuming that people’s preference to move straight prevails over their preference for choosing the shortest distance (Ratti, 2004). While in an open space the shortest
and straightest route may coincide, this is mostly not the case at the neighbourhood scale. The tendency to move straight is more likely to be relevant in areas where most pedestrians are visitors, and thus visual connectivity (legibility) is more relevant. It is less likely to be relevant in residential precincts where most pedestrians have a well formed mental map of the area. Nevertheless, both the straight-line and shortest-distance assumption are reductionist, and discount aspects of walking that are non-utilitarian, driven by curiosity, exploration, excitement (Cullen, 1961).

While in space syntax literature the relevance of physical distances has been generally dismissed, this has been done on the basis of comparisons between pure topological and a combination of topologic and metric attributes (Hillier and Iida, 2005), rather than the basic spatial concepts of permeability and pools of use (or walkable catchment). The lack of distinction in the literature between permeability and connectivity, and the use of proxy measures that do not directly measure permeability, adds a further layer of confusion (Pafka and Dovey, 2016).

In the following the contrast between topological integration and the metric properties of permeability and pools of use (Jacobs, 1961) will be explored, using the advanced metrics of area-weighted average perimeter (AwaP) and interface catchment (Pafka and Dovey, 2016). AwaP is superior to previous measures in that it registers the effect of both block area and perimeter, ensuring that the impact of a large impermeable block is not lost in the average. Interface catchment, a derivative of metric reach (Peponis et al., 2008), takes into account the actual morphology of the urban tissue (i.e. street width and open space), and is focused on the morphological element that is directly linked to streetlife - the public/private interface. Figure 3 compares the way a single morphology with heterogeneous block size can be measured and mapped according to integration, catchment and permeability. The model shows an orthogonal network of one square kilometre. Integration shows a mixed pattern with high and low levels juxtaposed on intersecting streets with one of the most integrated streets adjacent to the most impermeable block. By contrast interface catchment peaks in the middle of the smaller blocks because it is reduced by proximity to either large blocks or edges. On the other hand permeability is highest at the top of the map, farthest from the large blocks. This figure demonstrates how much of a different measure integration is than either catchment or permeability.

![Figure 3 - Integration, catchment and permeability: three methods / one morphology. (Diagram developed with Kim Dovey)](image)

It has been argued that properties of urban networks are dualistic: metric at ‘local scale’ and topologic at ‘global scale’ (Hillier et al., 2007). However, it is not clear how the local scale is defined, whether there could be relevant intermediary scales between the ‘local’ and ‘global’, and whether the distinction is progressive or at a threshold scale. Within recent research, increasingly axial integration properties are combined with metric properties, by limiting the integration radius to a given metric value (Al-Sayed et al., 2014). This caps problems related to the implicit high integration value attributed to very long straight streets in grid networks and high sensitivity to the definition of the study area boundary, also known as the ‘edge effect’
(Ratti, 2004). As such thresholds (of 400, 800, 1000 metres) are arbitrary, typically multiple values are tested in search for finding correlations with other morphological or social indicators. This is a peculiar hybrid method, that would assume that integration (visual or walking) stops at a fixed threshold value, rather than fading gradually, as suggested by behavioural observation and research (Pushkarev and Zupan, 1975; Gehl, 1987).

Further attempts to address such critique within space syntax include proposals to incorporate linear topologic (space syntax), node topologic (conventional graph) and metric attributes of networks (permeability) into a complex model (Batty, 2013: 179-244). However, the differences between metric, linear and node topologic properties are lost when converted to numbers. This is perhaps most evident in the accessibility ‘heat maps’ of street networks, where the linear topologic properties of street segments are converted into numeric values that are then spread out on a map starting from the centre of each axial line (Batty 2013: 204-205). Such hybrid approaches highlight the risks of converting geometry to algebra and then vice-versa without losing the connection with the physical space that is supposed to be represented and understood. The combination of mapping and algebra is a key aspect of space syntax that has been a source of confusion, as the maps show accurate geometric relations while the displayed topologic values ignore them.

4. AXIALITY AND SMOOTHNESS

A different kind of limitation of the axial space syntax approach is revealed by the various attempts to model smoothly curved and sinuous paths (Fig.4a). The process of abstracting curved streets to axial lines has a significant degree of arbitrariness (Batty, 2013). Their representation as a series of short axial lines (Fig.4b) leads to much lower integration values than a single straight street would have, even if the experienced difference is minimal. One alternative approach is to consider changes in direction below a threshold angle as insignificant (Figueiredo and Amorim, 2005). In such a model a meandering street like Broadway is represented as a single axial line (Fig.4c). A key problem however is that the threshold value for discounting angular turns is arbitrary, while visual continuity is gradual and dependent on street width.

In response to the same problem another alternative version to conventional axial analysis was proposed in the form of the ‘angular segment analysis’ that differentiates between various degrees of turns (Al-Sayed et al., 2009). The popularity of this method is due in part to the practical advantage that it can rely on broadly available street centreline data (Turner, 2007). The ‘angular shortest path’ is the one that minimises the degrees of angular turns, rather than the number of turns (fig4d). In other words the assumption here is that three 30° turns equal one 90° turn. This however is questionable given that the distance between turns can be of any length.

Yet another approach is the named-street topological analysis, where a street semantically identified as continuous is represented as a single entity (Fig.4e) regardless of the number and configuration of straight segments it is composed of (Jiang and Claramunt, 2004). Here the problem of setting an angular threshold for continuity is deferred to formalised semantic expressions. While this approach may appear broader for acknowledging some semantic dimensions of social space, it does so only in a simplistic way, instrumentalising one particular semantic dimension in order to build a computable network model.

Besides axial lines and segments, a third key type of street network model is based on routes (Marshall, 2005: 111-115). A computable approach labelled ‘intersection continuity negotiation’ has been proposed by Porta et al. (2006) who define spatial elements based on the most easily negotiated paths, considering that at each intersection the straightest direction is chosen (Fig.4f). A key problem here is that the result will largely depend on where the computation of paths begins, that is where one enters the network.
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While all these models and metrics are different, what they have in common is the attempt to translate smooth urban conditions into a striated measurable model, to iron-out ambiguities, hybrid and transitory conditions. They are reductionist, eliminating conditions of liminality, porosity and complexity, recognised as key attributes of urban intensity (Benjamin and Lacis, 1978; Sitte, 1889; Franck and Stevens, 2007). This is a similar problem as the use of cellular space syntax models for the analysis of fluid continuous interior spaces by converting them into models of clearly segmented spaces (Dovey, 2008: 61-83).

5. DISCUSSION
In actual cities, each of the limitations described above appear concurrently. In the following example all three types of limitations of axial models are exemplified based on a 1x1km frame of Amsterdam capturing part of the city core and the canal zone (Fig. 5a). The city core has irregular sinuous streets and small blocks as typical for informal settlements and medieval European cities. The ‘canal zone’ is defined by multiple regular polygonal rings around the core. This is typical for 17th-19th century urban extensions, such as in Vienna, Milan and Budapest. Translating the morphology into an axial model is problematic, because if it is based on ‘lines of sight’ the canals would need to be dismissed, but if based on access they need to be treated as city blocks. This highlights the problem of abstracting street sections to their axial lines. Similar problems become evident for wide boulevards with a median strip, or streets with a physical barrier along the axis. Some of these streets are easier to cross than others, and it is impossible to set a clear threshold as to when a wide street breaks down into two parallel streets.

Figure 4 - Variations of the space syntax integration model.
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Moving from the micro-scale to the neighbourhood-scale, reveals how representing continuous meandering streets as multiple axial lines doesn’t correspond either to lines of sight nor to access conditions. The axial integration map (Fig. 5b) shows the canal zone as more integrated than the city core because of its straight streets, despite blocks being much larger. The polygonal rings are shown as less integrated where they turn in smaller increments. The named-street integration map (Fig. 5c) shows both the sinuous main streets in the core and the streets along the canals as highly integrated. This is entirely different from the integration map, and shows how meandering medieval streets and streets along canals are socially understood as continuous. The angular segment integration map (Fig. 5d) shows a less differentiated pattern, with the radial streets linking the canal zone to the core as the most integrated, again a very different outcome to the previous two maps. While each of these methods differ from each other, they are also very different from patterns of catchment and permeability, that are highest in the old core and much lower in the canal zone.

Through a series of models (Fig.2-5), it has been shown that the abstraction of streets to their axial lines poses several fundamental problems. First it eliminates the street section with its public-private interfaces, footpaths, benches and trees - all key elements of streetlife. Thus it does not recognise that the social logic of space is not just longitudinal but also transversal across the street. Second, it ignores permeability and interface catchment as key morphological attributes linked to walkability. Comparing these measures suggests that integration maps can be to analyse walkable access at neighbourhood scale. Third, such abstraction translates smooth urban conditions into a striated measurable model that irons-out ambiguities, hybrid and transitory conditions. This is a problem shared with much research based on statistical analysis in the fields of health and transport that seeks to establish direct correlations between a ‘walkability index’ and levels of walking. Such reductionism eliminates conditions of liminality, porosity and complexity, recognised as key attributes of urban intensity at street level.

Figure 5 - Smooth morphologies in Amsterdam through three methods of space syntax analysis
Spatial syntax integration measures can be useful in studying larger urban networks, as they capture the morphogenetic tendency of busy streets to become straightened (Bosselmann, 1997; Kostof, 1999), but this is just one of many socio-spatial processes that shape cities. In order to better understand cities and their movement economies, a broad and open theoretical framework is necessary (Kärrholm et al., 2017; Dovey et al., in press), and correspondingly the use of a multiplicity of research methods. Spatial syntax analysis will be more useful, the more its limits are better understood.

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#103  
**NATIONAL SCALE MODELLING TO TEST UK POPULATION GROWTH AND INFRASTRUCTURE SCENARIOS**

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**ABSTRACT**  
This paper describes an exploratory methodology used to study the national scale issues of population growth and infrastructure implementation across the UK. The project was carried out for the Government Office for Science in 2015, focusing on two key questions: how could a "spatially driven" scenario provoke new thinking on accommodating forecast growth, and; what would be the impact of transport infrastructure investments within this context.

Addressing these questions required the construction of a national scale spatial model that also needed to integrate datasets on population and employment. Models were analysed and profiled initially to identify existing relationships between the distribution of population and employment against the spatial network. Based on these profiles, an experimental methodology was used to firstly identify cities with the potential to accommodate growth, then secondly to allocate additional population proportionally. This raises important questions for discussion around which cities provide the benchmark for growth and why, as well as what the optimal spatial conditions for population growth may be, and how this growth should be accommodated locally.

Later the model was used to study the impact of High Speed Rail. As these proposed infrastructure changes improve service (capacity, frequency, journey time), rather than creating new topological connections, the model was adapted to be able to produce time-based catchments as an output. These catchments could then be expressed in terms of the workforce population within an hour of every city (a potential travel to work area), as well as the number of employment opportunities within an hour of every household. 

**Keywords**  
Urban axes, geometric characteristics, spatial permeability and ductility, topological accessibility.

**KEYWORDS**  
integrated urban model, UK, population growth, public transport, spatial network analysis
1. INTRODUCTION
This paper sets out a highly experimental case study application of Space Syntax modelling to real-world, macro-scale, strategic thinking. In 2015 the Government Office for Science Foresight group launched a Future of Cities research programme. This programme studied all aspects of cities, how they might change, and what the impacts might be with a view to inform decision making at the current time. A Lead Expert Group (LEG), which included Space Syntax Ltd, oversaw the production and publication of a total of 38 Reports, Working Papers and Essays (which can be found at https://www.gov.uk/government/collections/future-of-cities).
To contribute to LEG workshops focussing on growth and transport infrastructure scenarios, two modelling exercises were undertaken to ask how a “spatially driven” growth scenario could provoke new thinking on accommodating forecast growth, and; what would be the impact of transport infrastructure investments within this context.
These two pieces of work were carried out sequentially, as different studies, and this paper has been structured in two parts to describe each in turn.
The first looks at UK population growth up to 2037, and used a UK wide spatial model to begin to profile existing spatial conditions in order to provoke new thinking on how population growth could be accommodated through existing, unseen, opportunities.
The second study, developed this model in to a more sophisticated Integrated Urban Model, combining multiple transport networks, population and employment data, and assigning speeds to segments to carry out time based analyses.

2. PREVIOUS RESEARCH
This study raises questions around relationships between population size and city outcomes. These relationships have been explored in socio-economic terms, however these studies lack the more sophisticated descriptions of space possible using Space Syntax techniques. Cities are not isolated entities but rather they sit within a wider regional and national complex network (Hildreth 2006). Their success in attracting and sustaining people and jobs depends a lot on the linkages that exist between them and to all others (Turok 2004). This is why the space syntax approach to understanding cities as a spatial network is important.
In “The Origins of Scaling in Cities” (Bettencourt, 2012) Bettencourt concludes that a range of outcomes, both positive and negative, are increased disproportionally as population grows. Through analysis of 415 urban areas in the United States, outcomes including GDP, Employment, Patents registered, were seen to scale super linearly, that is at a ratio greater than 1. In contrast to this, UK cities did not consistently follow these patterns (Bettencourt and Lobo, 2016). This was partly as a result of sample size, however Birmingham and Manchester are noted as clear examples where levels of economy and employment are too small in relation to population size. In some regards this is not surprising, US and UK cities have emerged from different social, political and economic contexts, the sample size of UK cities is small (15 cities above 500k), and does not include a spatial characterisation of the city, especially its position within a wider network of smaller towns and settlements. Both of these studies are based on the definition of cities as functional urban areas and do not take into account characteristics of the spatial network or its change in intensity.
Research carried out at UCL (Serra et Al, 2014) showed that there are indeed spatial relationships between UK cities and a range of outcomes: Across the UK, node count at 2km correlates with the distribution of employment, with more jobs found in areas of high node count. The correlation with node count was higher than that between employment and population, indicating that spatial characteristics are a stronger factor in employment distribution than population. The same research also found that population was found to correlate highly with node count at 10km, while affluence as defined by Serra et Al (2014) was found to correlate with node count at 100km.
The findings indicate that spatial conditions across multiple scales should be considered when developing a growth strategy. Further, creating cities that have higher spatial densities at 100km, 10km, and 2km replicates some of the spatial conditions associated with more economic activity, more economic output and more economic affluence.

Further relationships between the spatial characteristics of cities and their economic performance are also set out by Versluis and Law (2015). This study used commuting data collected through the Census to understand movement flows between cities. Whilst strong relationships were found between integration at 5km and both population density ($R^2=0.83$) and workplace density ($R^2=0.82$), there were complexities associated with the specific characteristics of commuter movement: “The difference between being a commuter city (Wigan), a city that attract commuters from nearby (Oxford) or a city that attracts commuters from afar (Norwich) appears to be influenced by the balance of city size, density and its regional connectivity.”

3. PART ONE – UK POPULATION GROWTH SCENARIOS

This stage of work concentrated on trying to understand how forecast growth scenarios relate to existing socio economic-patterns, and to develop an alternative spatially driven growth scenario.

The Government Office for Science (GOScience) appointed consultants to develop economically driven population forecasts as an alternative to the official Office for National Statistics (ONS) 2037 growth scenario.

Three further scenarios were generated on the basis of economic analysis:

- Major city empowerment
- London-centric
- Smaller cities driving growth

Spatial modelling was used to visualise the impact of these four growth scenarios. The specifics of these scenarios are not described in any detail in this paper beyond the following critique of their approach:

Current ONS forecasts are based on assigning the level of growth recorded between Censuses to the future. There are many issues with this technique, which include failing to take account of exceptional circumstances, outside influence, or to take any strategic approach to distributing or planning growth. These scenarios do not consider existing relationships to and between concentrations of population or employment, which may already exist where a city is well connected regionally, or if regional scale infrastructure projects such as HS2 or 3 are delivered. The impact of this process is potential inefficiency, or less than optimal results - there may be some parts of the country which have a higher capacity for growth than is being used, while some proposed growth is at risk of failing, or producing less effective economic impacts where it is not supported by the right spatial conditions. Furthermore, growth provides an opportunity to address existing problems in cities, however these will continue to go unaddressed through this approach.

Space Syntax analysis has been used to demonstrate how cities function simultaneously across multiple scales. It was proposed that this understanding of spatial structure at different scales could be profiled against population and used to develop growth scenarios. Some city centres may have a node count at 2km proportionally higher than its population, indicating they could support population growth. This could improve the functioning of the city centre, without requiring major investment in infrastructure. Alternatively, some cities may have very weak core areas, a condition that could be addressed by intervention in the centre. By intensifying or repairing this condition, it would not only improve the existing city but also allow it to accommodate a higher population.

Similar thinking can be applied to the city and regional scales. Some cities could support higher populations in their wider area or hinterland if the connections and structures between them
are strong enough. There may also be cities with a suitable balance between centre and urban area, in which case balanced growth is required.

When these opportunities and weaknesses can be seen, decisions can then be made around how growth could be accommodated, and how this might begin to relate to current relationships between cities and networks of cities.

Current growth scenarios, and distributions of population, do not begin to develop this level of specificity in terms of a strategy, nor do they begin to link the implementation of infrastructure to existing opportunities or as catalysts for growth.

A fifth “Spatially driven growth scenario” was therefore proposed by Space Syntax ltd, based on optimising the relationships between existing spatial characteristics and population distribution. This section of the paper explains how this spatially driven growth scenario was developed.

3.1 METHODOLOGY

To test how growth scenarios compare to current spatial characteristics a model of the entire UK was constructed using GIS software. This task itself is a major undertaking that was only possible based on the availability of open datasets, and modelling at a suitable level of granularity.

As a base, the OS Meridian Line data set was used. This is very similar to a road centreline map, however motorways and dual carriageways have been simplified to remove complicated motorway junctions and to reduce parallel highway lanes into a single line. This provides a very suitable base to use for Space Syntax modelling where the number of street segments needs to be as few as possible.

To this base, the current inter-city rail network was added. When this mode of transport is used to connect cities, it could be argued that the cognitive process of way finding is different to when people move through a city on foot, by bike or by car. The cost of using this network between cities is less likely to be angular, and more likely to be time based. However, as a purely spatial model was being used at this point these connections were added to reflect the topological nature of the direct link between stations. To reflect this, these connections were added in to the model so that they directly connect the locations of each station instead of following the exact path of the railway between stations, which would increase the number of segments in the model and add angular cost. For example, London St Pancras is connected by a single line to Birmingham New Street, effectively making them one step from each other. It should be noted that this would not now allow the same model to be used to process choice measures, and these were created in a model only including the road network.

Figure 1 - Unprocessed spatial network model of UK created from OS Meridian Line data.
The models were processed using Depthmap. For this piece of work the measure of node count was used across many scales (2k, 5k, 10k, 20k, 50k, 100k). Node Count is defined as the following:

\[ NC(R) = \sum n_i(R) \]

where:
NC is node count
n is number of nodes
R is the radius

A period of exploration then used these measures to profile the spatial characteristics of cities against other socio-economic datasets. These socio-economic datasets were provided at the level of the Primary Urban Area (PUA), which required them to be combined with the spatial model. There is a major mis-match in the granularity of data provided at the PUA level (which is coarse), and the spatial model (which is fine). One of the core issues is that the PUA boundaries do not accurately or consistently follow urban form. To combine these datasets, further exploration was carried out in to the way that cities can be spatially defined, and how closely these definitions relate to the PUA boundaries.

PUA boundaries are defined by taking areas where buildings are within 200m of another building, and then adjusting these boundaries to Local Authorities. As a result, some PUAs do not logically follow the built form of the city. Norwich (shown below) covers a very large area with the city itself occupying a very small part of this. The spatially contiguous form of Manchester is split into five smaller PUAs, while the built form of Bristol lies half inside and half outside a PUA.

![Figure 2 - Norwich PUA boundary (shown orange). The urban extent of Norwich (outlined in red) is only a very small proportion of the PUA.](image)

The clearest physical definitions of cities were formed by combining a measure of node count with a measure of population density, collected at the Lower Super Output Area (LSOA) level. Identifying segments that measured a node count of more than 100 segments at 2km, and which also recorded population densities above 5 p/ha, produced a more visually accurate description of urban form. When the population within the LSOAs identified by this method were aggregated they were found to correlate very strongly with the population of the PUA, meaning that these definitions could be used to profile spatial characteristics more precisely if required. However, while this approach defined cities more clearly, these boundaries could not be combined with any socio-economic datasets.
As the PUA boundaries were retained, spatial data had to be assigned to these boundaries. A number of methods were tested to identify the best way to aggregate spatial data, and included using the maximum, minimum or average value of segments within the PUA. Through testing, the sum of all segment values within the boundary gave the strongest correlations against factors such as population.

3.2 EXISTING RESULTS

The combined model (meridian line plus strategic rail connections) was able to replicate the findings of Serra et al. 2014.

![Figure 3](image1)

Figure 3 - Scatters of population vs node count (left), employment density vs node count (centre) and affluence vs node count (right), Serra et al. (2014).

In addition some further analysis was briefly carried out. This identified a correlation of 0.76 (R²) between node count at 10 km and Gross Value Added (GVA). GVA, as defined by the ONS, measures the contribution to the economy of each individual producer, industry, or sector in the UK.

Population Density, as opposed to Population, was seen to correlate highly against node count at 2 km.

3.3 GENERATING A GROWTH SCENARIO

An alternative “spatially driven scenario” was developed based on matching the spatial characteristics of PUAs to future population.

Existing PUA populations were profiled against node counts at 100 km, 10 km and 2 km. Population is always shown on the y axis while node count is always shown on the x axis. The red line identifies the line of best fit. These scatters formed a baseline to compare scenarios against.

![Figure 4](image2)

Figure 4 - Scatterplots profiling UK PUA population against node count at 100 km (left), 10 km (centre) and 2 km (right).

Across all scales London is consistently above the line of best fit, indicating its population is very high in relation to node count. The scale that this difference is greatest is at 100 km.

This begins a discussion around how a strategy could start to respond to existing conditions, and specifically, not just where should new growth be accommodated, but what can be done to make existing cities better.
Where a city falls on the line of best fit it indicates that population size is proportional to the node count of the city at that scale. Where a city is below the red line, it shows that the city has a high node count, but that the population size is not proportional. These cities have capacity to grow.

Where a city is above the red line, it indicates that the population is proportionally higher than the node count. These cities require changes within the spatial network to allow the city to function efficiently. This change could include regional infrastructure connections, urban extension, better connections from the city to its centre, or improvement of the centre itself. These changes need to be made before these cities can be considered for growth.

Scatters were generated in sequence from regional (100km), to city (10km) to centre (2km) scales. Populations were increased proportionally for the regional scale, before re-profiling the new population against 10km, assigning more population change, then re-profiling the updated population against 2km and repeating the proportional allocation.

The model was then updated to include HS2 and HS3, to see what opportunities will emerge further ahead in the future.

The total population increase accommodated by cities at each scale was calculates as follows:

- Regional scale capacity (100km) 3.9m
- City scale capacity (10km) 1.0m
- City centre scale capacity (2km) 0.3m

This accommodated over 80% of ONS forecast growth in existing cities, leaving an unallocated population total of 1.1m.

To this point, the process deals only with cities that can accommodate more growth. It has not yet addressed cities above the line of best fit where the spatial densities at 100km are not high enough for the population (such as Birmingham). To improve the regional scale connectivity of cities above the line requires major change. This change could be implemented through transport infrastructure.
This approach follows a principle that a pre-determined model or overall hierarchy of cities will not be imposed, but that growth will be located where opportunities already exist. The two maps below showing where growth has been added (left) and total population (right), show that London remains significantly larger than any other city. Generating or fundamentally changing this existing hierarchy of cities to create a city which is more similar to London, or which creates a more distributed network hierarchy is a major decision with feasibility restrictions (cost, physical) and economic, social and political impacts.

Figure 6 - Thematic maps showing percentage growth by PUA (left), and resulting total population (right). Many PUAs recording very high growth rates remain small within the UK hierarchy of cities.

3.4 PART ONE - DISCUSSION

This scenario does not take account of any factors outside spatial characteristics and it has a number of implications that require better understanding.

The spatially driven growth scenario creates something that is radically different. This scenario does not make reference to population or employment trends, but concentrates growth in locations where the spatial characteristics associated with economically successful cities are already in place. Whilst these cities have the infrastructure, they don’t currently have the employment, and many of the PUAs where growth has been allocated tend to be shrinking cities. The reasons for this shrinkage have not been investigated but many have well documented economic struggles. While this approach cannot provide an answer to these issues, it can be used to indicate where policy intervention or incentives are more suitable than physical intervention.

 Whilst growth has been assigned to cities with strong spatial characteristics, there remain a number of cities with poor spatial characteristics. This limits the growth to London and other major cities. It also identifies cities, such as London, where spatial infrastructure improvements are required to support the existing population. London itself may be the problem, and it is an outlier in spatial, economic and population terms that there could be argument that it does not set a useful comparison for other PUAs.

This also begins a conversation around both the factors that have been profiled in order to allocate population growth, and the fact that all PUAs have been used to define the target line. With more time available, analysis of factors such as quality of life could have been used.
Rather than taking the line of best fit across all cities, which in effect will create more average cities, defining the target line based on a selection of the highest performing cities would make a more robust scenario.

Because existing PUAs were profiled to accommodate growth, the study did not identify any places for entirely new settlements.

Finally, growth was allocated proportionally starting from the regional scale (100km). One of the results of this is that smaller cities between large cities accommodate a lot of growth. This is an interesting subject for further consideration in relation to the debate around what size of city, in terms of population, is optimal. The work of Bettencourt suggests that (positive and negative) outcomes in larger cities are greater, and this would suggest that a strategy should aim to concentrate growth to a few larger cities. By contrast, the result of the approach tried here increases the size of many smaller cities close to large cities, rather than further increasing already large cities. Whilst there are differences between the two studies in this respect, where they share a similarity is that they identify Manchester and Birmingham as underperforming – Bettencourt on the basis of a smaller GDP in proportion to population, our study on the basis of having lower levels of spatial density in proportion to its population.

4.0 PART TWO – UK INFRASTRUCTURE SCENARIO TESTING

The key question being studied during this stage of work shifted to whether the right transport infrastructure is in place, at the macro-scale, to support cities and create strong networks of cities. The working assumption is that this can be achieved by providing high levels of residential population with access to high levels of employment opportunity.

Transport connections must not compromise the local scale networks, which must either remain intact or be improved to fully optimise investment in infrastructure and generate maximum benefit. However such benefit is only possible if the macro-scale network is in place to begin with, and this is the subject of this piece of work.

Three questions were investigated through this work:

- How infrastructure proposals strengthen relationships between PUAs, surrounding populations and other PUAs, and;
- How infrastructure proposals improve access to employment opportunities across the country?
- What transport infrastructure intervention is required to create the best outcome?

In answering these questions a total of eight infrastructure scenarios were developed and tested (shown below). However this section does not concentrate on showing how these were generated, or how they performed, but instead talks about the methodology used to model and analyse them, and some of the findings on existing conditions.

Figure 7 - Infrastructure scenario options tested (proposed improvements shown in red).
4.1 METHODOLOGY

The focus of this stage of work was on the impact of transport infrastructure in terms of access to a working population, and access to a number of jobs. The major measure was therefore based on understanding the catchments of PUAs through all modes of transport, and the number of people and jobs within these catchments.

A consistent measure of cost is required to combine the impacts of travel on foot, by car or by train. As the decisions involved in navigating on foot, by car and by train are different, time cost was used to calculate isochrones rather than metric or angular cost.

For this piece of work the spatial model from the earlier growth scenarios study was developed further by adding the entire UK rail network, adding additional unlinks to separate this from the road network and adding speed to every node in the combined network.

Each network has a categorised hierarchy, allowing average speed assumption to be added to each element of the network. The road network (generated from the OS Meridian line) consists of four categories of road, each with a different speed limit. Assumptions on speed have been applied at 80% of the speed limit:

- Motorways (56 mph or 90 kmh)
- A Roads (48 mph or 77 kmh)
- B Roads (20 mph or 32 kmh)

The rail network was assembled from different sources including Ordnance Survey, High Speed 2 Limited and One North 2014. Each category of rail line was then allocated the following assumed average speeds, based on around 80% of maximum speed:

- High Speed railway (100 mph or 161 kmh)
- Principal railway (60 mph or 97 kmh)
- Local railway (30 mph or 48 kmh)

Further population and employment data has been added to enable time-based catchments from each PUA allowing relationships between employment and population to be used as the basis for a scenario comparison. The InFuse LSOA dataset, containing more than 40,000 areas covering the whole of the UK and Census data were used to add population data. Employment data used in this study is limited to that found in PUAs, which accounts for 59% of total UK employment (Cities Outlook 2015) ref http://www.centreforcities.org/publication/cities-outlook-2015/.

Using the Integrated Model, the population and employment within one hour of each PUA (using all modes of transport) was calculated for a Baseline Scenario, then for additional scenarios in which changes to the rail network have been made.

This was carried out using ArcGIS Network Analyst to build the network then generate a catchment for each PUA. The resulting catchments were then used to carry out a series of queries which include:

- residential population within a 60-minute catchment of each PUA

\[ \text{Pop}_{\text{PUA}}(60\text{mins}) = \sum \text{R}_{\text{LSOA}}(60\text{mins}) \]

where:
Pop PUA is the number of residents within an hour of that PUA
R LSOA is the number of residents per LSOA within 60 minutes
• employment numbers within a 60-minute catchment of each PUA

\[ \text{Emp}_{\text{PUA}}(60\text{mins}) = \sum \text{E}_{\text{PUA}}(60\text{mins}) \]

where:
Emp PUA is the number of jobs within an hour of that PUA
E PUA is the number of PUA based jobs within 60 minutes

• access to PUA based employment from all LSOAs

\[ \text{Emp}_{\text{LSOA}}(60\text{mins}) = \sum \text{E}_{\text{PUA}}(60\text{mins}) \]

where:
Emp LSOA is the number of PUA based jobs within an hour of every LSOA
E PUA is the number of jobs in each PUA

These results can be visualised showing where catchments overlap (1), colouring all PUAs according to population or employment within these catchments (2 + 3). A more complicated process was used to sum the PUA based employment opportunities within an hour of all parts of the UK shown at LSOA level (4). All of these measures could also be visualised as scatters and graphs.

4.2 EXISTING RESULTS
Scatters of existing population and employment within an hour of all PUAs are shown below:

Figure 8 - Visualisation of integrated model. 60 min catchment from all PUAs, darker colours indicates an overlap of more catchments (Left), PUA based Population within 60 mins of each PUA, with red showing higher and blue showing lower numbers (centre left), PUA based jobs within 60 mins of each PUA, with red showing higher and blue showing lower numbers (centre right), and, total number of PUA-based jobs within 60 mins of every LSOA in the UK, with red showing higher and blue showing lower numbers (right).
This reveals four clusters which can be loosely characterised as follows:

4.2.1 CAPITAL AND SATELLITE CITIES
The highest populations and employments are found in London, however the smaller PUAs of Aldershot, Crawley, Luton, Chatham and Reading benefit significantly from their proximity to the capital, making them satellites. Capital and satellite cities already share population and employment, limiting immediate catchment benefits from improved railway infrastructure.

4.2.2 CITY NETWORKS
Cities within the peak ring are grouped together in the middle of the range of population and employment figures. Due to the physical proximity and strength of the connections between them, their opportunity to have access to higher numbers of jobs and employees is exploited by improved railway infrastructure between the cities.

An interesting comparison can be seen between the Peak Ring cities and London; while the Peak Ring is formed from many PUAs, providing access to a greater number of cities, the number of jobs within these cities is not as great as within London. In terms of proximity to employment,
there is a major benefit to being within the South East.

4.2.3 EDGE CITIES

The lowest population and employment figures are found in the more isolated PUAs. Cities in the North East of England and Scotland, are so far from other PUAs and other settlements) that improvements to infrastructure (at current levels of “high speed”) may not be enough to connect them to more people or jobs.

4.2.4 HIGH PERFORMING CITIES

A cluster of Cambridge, Oxford, Milton Keynes and Southend can be seen to provide far higher amounts of employment to population than is proportional elsewhere. There may be a range of factors influencing this: a catchment analysis will always create a threshold effect where some cities are either just inside or just outside a boundary, these cities all fall within the catchment of London. Because datasets have only been used at the PUA level, these cities may be supported by a range of smaller settlements that are outside the definition of a PUA (and so are invisible in the data) but which still hold a relatively large population.

4.3 SCENARIO TESTING

A total of five alternative scenarios were generated and tested by adding new rail links or increasing the speed on existing connections. Assessing the impact of scenarios could best be done using the LSOA level analysis of employment within 60 minutes, and the corresponding graph.

Figure 10 - Impact testing scenarios using maps to visualise employment within 60 mins of all PUAs, and graphs to compare options in terms of the cumulative percentage of residents within an hour of PUA based employment. In the most well performing option 40% of UK residents could have 10% more jobs within an hour.
Without going into the detail of each scenario, general findings across the country were that most improvements could be seen in the middle of the distribution. That is, the cities with access to a high amount of employment were not seen to benefit too much, neither were those with very poor access.

This would explain what is happening to the Capital and Satellites, and Edge Cities clusters described earlier. The edges are so far from anywhere that without major increases in train speed, an hour’s journey does not reach any significant PUAs. This could partly explain the case with the Capital and Satellites: the network has already developed to create multiple strong connections to London, and while some improvements might connect parts of Birmingham to London within an hour, the location of the station and integration with local scale networks does not make a significant impact on the country wide access to jobs.

The parts of the distribution where improvements can be most clearly tend to be where changes to the network have strengthened connections between cities that are physically close.

4.4 PART TWO - DISCUSSION

This catchment-based analysis of the UK's system of cities presents an interesting counterpoint to the discussion on the distribution of city size by population. The UK has a long tail distribution of city size by population, however when it is profiled in terms of the number of employment opportunities and population within one hour, the shape of the distribution becomes much more linear. One interpretation of this finding is that the UK's cities work in smaller, regional scale networks of cities, rather than as a singular national scale network.

There are also exceptions such as Oxford, Cambridge, Southend and Milton Keynes which have proportionally lower residential populations but a very high number of jobs. As with the Growth Scenario work, this may be the impact of PUA level data obscuring the relationship to networks of smaller supporting towns and villages.

Using this more sophisticated description of cities and city networks, again, we find similarities with the work of Bettencourt, specifically that Birmingham and Manchester continue to under perform against the average (defined by the line of best fit) when the number of jobs within an hour are plotted against the population within an hour.

There are of course limitations to this methodology; when catchments were run, they were based on travelling as far as possible within an hour only taking speed into account. Analysis does not therefore take into account considerations such as capacity, frequency of service, congestion, financial cost of service etc. While this creates some restrictions, it could be argued that it provides a useful understanding at the strategic level of decision making by showing the potential reach of cities. Considerations of cost, frequency and capacity do need to be taken into account, and these will affect the ultimate success of the project, however they inform issues of how the infrastructure is operated and used, rather than where it is and what it connects.

The measure of PUA based employment within an hour of every LSOA is interesting within the UK context. An established measure used within transport planning is the Travel to Work Area (TTWA). TTWAs are generated through the census and other surveys, and effectively provide a snapshot of where people live and work at any one time. This is likely to pick up the impact of some of the issues listed above such as cost and congestion. However, what TTWA do not show is the potential of infrastructure to connect people to other jobs. As a result, using it to make strategic infrastructure or planning decisions runs the risk of missing existing opportunities. Using the Integrated Model to calculate these "potential" travel to work areas can start to address this issue.
5. LIMITATIONS

There are some significant limitations to both elements of this work:

At the point in time when this study was carried out there were very few pieces of work within the Space Syntax community addressing either similar scale or outcomes. Consequently the work has been based on three measures that were identified as significant by Sera, Hillier and Karimi (2014). Working within the constraints of a short project, there was also very limited time or resource to spend on further, detailed exploration.

As a result the methodology should be caveated as being highly experimental in nature; it has been developed around only three very simplistic analyses for which it is very difficult to verify the impact of. Longitudinal analysis to validate the relationships between changes in the characteristics of the three analytic measures used here, and socio-economic outcomes would help. However, collecting the data required over the time scales involved in this level of city change, in a UK context, and to identify the causal mechanism would be difficult. It should also be re-stated that the aim of the work was to stimulate new thinking in relation to growth rather than to generate a new scenario which was only subtly different to those which emerge through the conventional methods.

6. CONCLUSION

Throughout both pieces of work the Integrated Urban Model was very useful. It allowed high level modelled output of multiple scenarios to be produced very quickly (within a matter of a few weeks), enabling discussion of scenarios and impacts to move beyond personal interpretation far more quickly. The range of output visualisations also proved very useful to work with a range of people from different professional backgrounds, each with their own preferences for statistical or graphic outputs.

In considering the suitability of this approach for other projects the issue of threshold effect has been raised and discussed. One approach which remains to be tested is to generate catchments across a range of thresholds, including for example 30 minutes, 60 minutes and 90 minutes. The resulting profile of how a city performs across many scales may help to develop the characterisation of cities further and remove some of the anomalies.

In addition, profiling cities against a range of outcomes should also be considered. Economic impact is one of many outcomes of a city, and in considering which cities we should learn from, we must also consider social and environmental outcomes. It should also be reiterated, that the strongest performing cities against these criteria should be taken as the basis for making changes to population, rather than the average.

Finally, the two studies could have benefitted each other if there had been an opportunity to revisit the growth scenario having carried out the transport modelling. This would have added an additional layer of sophistication and allowed a more complete scenario to be generated.

An interesting point of our work is the exploration of the concept of scaling from a network perspective firstly and how that could help us make urban planning decisions secondly. The work of Bettencourt measures scaling between the population and the various socio-economic-functional parameters of cities such as GDP and patents within an urban area boundary. A critique of Bettencourt’s work is the use of an urban boundary in measuring population where in reality the functional boundary of any city might be really different. Interpreting our work from a scaling perspective will allow a much better understanding of how population scales with different socio-economic parameters. For example, if instead of using population within a predefined urban area boundary we are measuring population within the network functional boundary, do super-linear scaling still hold? This has great implications on the benefits of density and agglomeration. As a result, more work is needed to understand how this works relate to the scaling literature.

Since completing the work it has subsequently been presented to the Department for Communities and Local Government, the Treasury and the Department for Transport. In most
cases, whether the discussion was in the context of housing or transport, conversation turned to opportunities to make “quick wins”. This underlines a major benefit of this approach, which is not just to make decisions based on an understanding of what spatial characteristics affect how cities work, but the potential to identify existing opportunities that cannot be picked up through current statistical methods used to allocate growth.

An interesting point of our work is we are exploring the concept of scaling from a network perspective firstly and how that could help us make urban planning decisions secondly. The work of Bettencourt measures scaling between the population and the various socio-economic-functional parameters of cities such as GDP and patents within an urban area boundary. A critique of Bettencourt’s work is the use of an urban boundary in measuring population where in reality the functional boundary of any city might be really different. Interpreting our work from a scaling perspective will allow a much better understanding of how population scales with different socio-economic parameters. For example, if instead of using population within a predefined urban area boundary we are measuring population within the network functional boundary, do super-linear scaling still hold? This has great implications on the benefits of density and agglomeration. As a result, more work is needed to understand how this works relate to the scaling literature.

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ABSTRACT

Architecture is defined by intentional design, while cities are the product of multiple human actions over a long period of time. This seems to confine us between a view of architecture as authored object and a view of the city as authorless socio-economic process. This debate goes back to the separation of architecture from its skill base in building craft that took place in the Renaissance, including its division from the processes by which cities are produced by clients, users, regulatory codes, markets and infrastructures. As a result, architecture is confined in exceptional cases to the status of iconic buildings, or more generally to the status of buildings as economic production. Currently, buildings and cities are appropriated by digital technology and ubiquitous computing as a way of managing the city’s assets. Digital technologies integrate designing with making, informational models of buildings with geographic information systems and digital mapping. What had to be separated from city-making practices in order to raise architecture to a different status is increasingly re-integrated through digital infrastructure. As for architecture, traditionally engaged with the design of objects rather than networks or systems, is deprived of relevance in shaping social capital, politically and intellectually sidelined. Focusing on the Piazza San Marco in relationship to the urban fabric of Venice this paper traces the interlocking spheres of self-conscious architecture, the institutional and intellectual resources mobilised by Venetian statecraft and the networked spaces of everyday action. It argues that the scenographic design of the Piazza annexed the urban structure of Venice, historiography and civic rituals to advocate a centralised city of ceremonial processions, exalting the state and the Republic. The intersection of architecture, theatre and the street reduced the complexity of the city into a theatrical set and used perspective to make it synoptically available to the eye. Tracing morphological paradigms of early modernity, this paper unravels the rise of architecture as an elitist practice parallel to the rise of the state, and a theoretical framework for theorising its relationship with the city.

KEYWORDS

Statecraft, architecture, theatre, evolutionary networks, cities, Venice

1. INTRODUCTION: BETWEEN AUTHORED ARCHITECTURE AND THE AUTHORLESS CITY

This paper reflects on the enduring gap between cities as authorless entities that emerge out of multiple actions of people over time and architecture as the outcome of intentional design. A large number of theories and manifestos have been produced in the 20th and 21st century as reactions to architecture’s autonomy and capacity to articulate visions about the city. In their participation in UN HABITAT III, a group of urbanists from the London School of Economics

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announced their visions for cities as counterpoints to Le Corbusier’s urban projects consisting of isolated blocks that break the diverse urban and social fabric. According to the three theorists, Le Corbusier’s ideas as expressed in the Charter of Athens have been reviled, but the model of development they established continues to shape cities around the planet. Presenting their vision in a document called ‘The Quito Papers’, these theorists argue for urban environments that possess the enduring tenets of porosity, complexity, synchronicity, informality and incompleteness (Greenspan 2016).

Ever since Jane Jacobs wrote her attack on modern city planning, architects, planners and urban designers have been criticising modernism in search of alternative models for urban vitality (1961). Concerned with the properties that make a good city, they have contributed to shifting the conversation outside the sphere of architectural discourse and design. At the same time advancements in complex theory and communication technology appropriate urbanity in order to manage the city’s assets, a wide spreading economic model of efficiency known as ‘smart cities’. This technological and managerial approach sees buildings and urban areas as entities that are ‘self-organising’, depriving architecture from relevance in shaping social capital. In addition, new methods of design generation using digital technology are taking the appearance of those self-organising processes, which underpinned the growth of the organic city. Both the resurgence of opposition to the Charter of Athens and these technocratic models testify that since the Renaissance we have failed to develop theories and techniques that address the relationship between authored architecture and the authorless city. For architecture to reclaim its scope as social discipline it needs to theorise its relationship with the social, the political and economic processes of context.

If self-organisation and informality represent the latest paradigm shift, defining a revolution in thinking, which tradition is being revolutionised? In this paper, I attempt to resituate architectural knowledge in order to overcome the gap between the above polarizations. Rather than looking at contemporary cities in an unstable form of continuous transformation, I focus on Venice, as encompassing a more stable stratigraphy of spatial organisation. More particularly, I analyse the Piazza and the Basin of San Marco, which in the 16th century encapsulated the transformation of architecture from practical art to liberal art, epitomising the origin of contemporary architecture and urban design. If the designs of the Piazza influenced one of the most significant moments in Western and cities, what are the mechanisms by which this was accomplished? How can the analysis of the Piazza contribute to reframing the discourse about the city as the collective outcome of society and architecture as the deliberate product of design? These are key questions each time architects, urban designers, planners are called to consider aspects of sustainable cities and heritage, particularly in light of contemporary definitions of tangible/intangible heritage based on a more inclusive approach that also involves community values (Psarra 2017a, 2017b).

The purpose of this paper is twofold: first, to visit a key episode in which architecture, the urban landscape and an entire city were conceived together as the means for communicating dominant values of memory, identity, history and as political instruments of control. Second, to revisit the roots of architectural and urban management at a time and context where Western architecture emerges as the legitimised vehicle for urban renovation, redefinition and regeneration of architecture and urban space in modernity. Through an analysis of the Piazza and the way in which it relates to the city as a whole, I argue that in collaboration with their patrons, the 16th century architects Jacopo Sansovino (1486-1570) and Andrea Palladio (1508-1580) used architecture to express the Renaissance ideals of civic unity and urban integration. The Piazza is the space where the Republic apparatus took active ‘stage’ in founding architecture as a discipline and as political tool. The purpose was to exalt the city-state and distinguish it from the collective and anonymous processes that had produced the organic
urban fabric. The difficulty of architecture to contribute new visions for urban vitality goes back to the scenographic definition of urban space that reduced the complexity the city into a single image. The confluence between architecture, theatre and the street defined the double role of urban space as everyday space and representational theatrical space in Humanist culture. The theatrical model of the square and the street became an instrument of urban control and regulation, for centuries influencing architecture and urban design. Fontana’s streets of Rome and Haussmann’s boulevards shared this common logic (Vidler 2011).

The paper is structured in four parts. The first part provides a brief description of the Piazza San Marco and the Basin, introducing the history of its transformations and major structures. The second, third and fourth part present the spatial analysis of the Piazza and the Basin in the context of the immediate area and the city of Venice as a whole. The final part provides a model for theorising architecture’s capacity to articulate a project for the city.

2. THE RENOVATIO URBIS: THE PIAZZA AND THE BASIN OF SAN MARCO

The marriage between theatre, architecture and the street goes back to the Renaissance at the time when major civic spaces in Italian cities were redesigned. It has its origins in the concept of scenography in the Renaissance, a term invented by Sebastiano Serlio (1475- c. 1554) in his second book of Architecture published in Venice, whose innovations gave Renaissance architects a way to bridge Vitruvius’ Roman theatre with architecture (1611). A number of theatres, buildings and squares were built at the time, still influencing the ways in which architecture and urban spaces are being designed. Arranged theatrically, urban piazzas used perspective to unify art, architecture, public space, and make them synchronically accessible to the eye. The physical configuration of the Piazza San Marco was the outcome of a long process of adaptations that had started in the 10th century. Yet, it reached a stage close to its present form in the 16th and 17th centuries through coordinated acts of conscious design. Configured to accommodate performances and processions, the urban transformations in the Piazza were in essence a major project of aggrandisement of the city, superimposing the ideal of a Roman forum on the medieval urban fabric.
The island of San Marco has a strategic position, controlling the entrance to the Grand Canal and the route towards the littoral islands that separate the lagoon from the Adriatic. Its focal point is the Piazza and the Piazzetta with the Ducal Palace and Basilica of San Marco, the Doge’s residence and private chapel (figure 1). The Piazza is enclosed on three sides by the loggia façade of the Procurators of San Marco who had the most prestigious status after the Doge, being elected for life with the task of looking after the Basilica. The Piazzetta forms an extension of the Piazza to the waterfront, flanked by the Palace on the right and Sansovino’s Marciana Library on the left side. Until 1846, when the railway line connected Venice with the mainland, the Piazzetta was the formal entrance to the city. When foreign dignitaries and ambassadors would arrive from the lagoon, the first view they would have was from the waterfront looking to the Piazza through the Piazzetta. The two columns at the water’s edge (Porta da Mar or Columns of Justice) would greet them, bearing symbols of the two patron protectors of Venice. The columns also marked the place where executions of criminals and spectacles would be conducted. The Piazza, the Piazzetta and the entire water expense of the Basin were the heart of ceremonious occasions, from processions to festivals, regattas and mock sea battles, expressing the ritual structure of society and the social order of justice. The entire area was shaped theatrically, staging rituals and public occasions since early times, but in the 16th century its definition as theatre became formalised.

An idea of how the complex looked in early days is through Fra Paolino’s map (c. 1346), showing a defensive compound that encloses the palace and the Basilica of San Marco. The original castle-palace was on the water’s edge, surrounded by a natural moat of canals, while the Basilica was facing a square, which was just half the length of the present area. At the west end of the square was a canal on the opposite bank of which stood the old church of San Geminiano. The first major transformation leading to the present appearance of the Piazza came in the 1170s with Doge Sebastiano Ziani (1172-1178). Ziani’s vision ‘was to create a vast Platea ...where all citizens would congregate in the form of an ancient forum legitimising his political choices’ (Foscari 2014). He doubled the length of the Piazza, created a continuous line of buildings around it for the Procurators created the Piazzetta, placed the two columns on the water’s edge and enlarged the Ducal Palace (Fenlon 2010). The next significant changes came in the fourteenth century, with the redevelopment of the Basilica and the Palace (1340). A triumphal arch between the Palace and the Basilica (Porta della Carta) was also constructed at that time (c. 1443), forming an official entrance to the Palace’s courtyard for foreign dignitaries. Finally, the construction of the Clock Tower (Torre dell’ Orologio) begun at the north side of the Piazza (1496). The Orologio was the most advanced astronomical clock in existence, celebrating the entry point to the commercial thoroughfare leading to the Rialto. The state of the Piazza at the turn of the fifteenth century can be seen in the famous woodcut of Jacopo de’ Barbari (1500), showing the central wing of the Orologio which at the time was under construction.

In the first decades of the sixteenth century, the Venetians intensified their efforts in improving the image of the city in inverse proportion to the declining political power of Venice. Membership in the Great Council (the political body that governed Venice consisting of noble men) became hereditary at the end of the 14th century, halting upward mobility and stabilizing the social structure of Venice into patricians, citadini and popolani (Romano 1987). With the defeat of the Venetians at the War of the League of the Cambrai (1508-1516), the circumnavigation of Africa (1498), the discovery of America (1492) and the fall of Costantinople (1453), Venice lost its dominance in trading networks, ceasing to innovate as an economic and political power. These changes brought a turn from naval commerce to land ownership in the Veneto, a major geopolitical project that led to innovations in land reclamation, irrigation and cartography, as well as a new building type invented by Palladio, the classical farm-house or villa. The second major project of the Venetian Republic was the investment in public works that saw the aggrandizement of the major civic spaces in the city, such as the remodeling of the Piazza San Marco.

An ambitious urban renovation (Renovatio Urbis) was inaugurated following the appointment of Jacopo Sansovino as state builder (1529) in charge of the entire area of the Piazza complex. Sansovino widened the Piazza and the Piazzetta, improving the position of the Basilica in relation.
to the other structures. He completed the *Procuratie Vecchie*, built the Little Loggia (*Logetta*) at the foot of the Campanile, the new government Mint (*Zecca*) facing the Basin just around from the Piazzetta, and begun the Marciana Library. He also proposed a unifying two-storey wing extending from the Library to the church of San Geminiano. This had the impact of turning the Campanile to freestanding monument and giving the Library a north façade on the Piazza. It was Vicenzo Scamozzi (1548-1616) and Baldassare Longhena (1596/97-1682) who completed this part of the project, realizing Sansovino’s idea for a wider Piazza and continuous façade around its fabric. The connecting section joining the *Procuratie Nuove* with San Geminiano was eventually demolished under Napoleonic rule in 1807 and replaced by an imperial ballroom.

The Basin had also changed over the 14th and 15th centuries, including the island of the Giudecca which was extended eastwards around 1330, creating a narrow canal between it and the island of San Giorgio, on which foreign dignitaries entered the city from the south. Towards the end of the 16th century Palladio’s churches - San Giorgio Maggiore (1565-1611) and the Redentore (1577-1592) - changed the aquatic realm, commanding views to the south. The two churches were completed in the early 17th and late 16th century, respectively. Longhena’s centralised church of Santa Maria della Salute (1631) was built next, in the strategic site adjoining the Customs House (*Dogana*) in Dorsoduro. Dominating views at the entrance to the Grand Canal with its towering dome, it added to the constellation of religious buildings that punctuate the Basin.

3. CITY-CRAFT: THE PRODUCTION OF SPACE AND SOCIAL IDENTITY IN VENICE

In contrast to the integrating visions of the Venetian Republic, the origins of Venice were in the archipelago of island communities, which after a long process of land reclamation were joined, collectively forming the compact city as a whole. The analysis of the canal and pedestrian networks (using angular segment analysis) shows that the squares (*campi*) of the islands with their churches, church towers and wellheads are interconnected at all scales (radii) through the pervasive network of betweeness centrality or choice (2012, 2013, 2014) (figure 2). This means that each time islands were joined a bridge was built in close proximity to steps, connecting the canals with the squares and the squares with each other. The pervasive centrality of the *campi* also indicates that they are the nodes in the intersection of Venice’s combined network of the pedestrian and canal infrastructure. The squares of Venice were social nuclei of semi-autonomous communities since early times, gradually coalescing to produce the amphibious city. Parish islands contributed as much to the development of local neighbourhoods as to the city as a whole through the patrician class, featuring as leading families in the islands as well as members of the Great Council (Howard 2002, Romano, ibid.).

If the measure of choice reveals that the logic that drove the development of the city was distributed into its many parochial centres, the measure of closeness centrality, or integration, shows that Venice had two major nuclei: the Rialto and the Piazza San Marco (figure 3). The former was the religious and ceremonial core, while the latter was the major trading centre of Venice. We know that the Venetian patricians had not only public office but also trading posts in the Rialto and their warehouse - *palace* (*fondaco*). The spatial measures of choice and integration therefore, express two powerful dualities in the social fabric: first, the twofold identity of the aristocratic class as merchants-officials of Venice, promoting republicanism within their own class and social hierarchy for the entire society; second, parochial identities of the parish communities, and civic identity through the central administration of the Republic. Venice was the outcome as much of the collective network of squares, canals and streets as of the hierarchical difference of the two urban centres from the rest of the islands. With time, collective social organisation shifted from the island communities and the spontaneous production of space to central administration. This transformation was in effect a superimposition, suppressing the local communities but in ways, which ensured the mitigation of social conflict. With time, legends and myths about the origin of the city were appropriated by Venetian historiography, forging the *Myth of Venice*, a collection of beliefs and official histories that described Venice as the most serene Republic (Muir, 1981).
4. STATECRAFT: THE MAP OF JACOPO DE’ BARBARI AND THE PIAZZA SAN MARCO

Before examining how the urban transformations in the 16th century changed the spatial structure of the Piazza, it is necessary to explore how its spaces and monuments were viewed at the time. A vivid representation is Jacopo de’ Barbari’s woodcut, one of the earliest demonstrations of Venice’s Myth, synthesising political ideology with the urban fabric (figure 4). Printed to the scale of a mural, the woodcut depicts Venice framed by the lagoon as a triumphant metropolis. Constructing a moralising portrait of the city, de’ Barbari’s map was part of the tradition of Mappae Mundi (medieval world maps) produced in the 15th century by Venetian cartographers. Two diagonal lines established by the wind rays emanating from the eight gods that circle the city organise the print, intersecting at the top of the Campanile in the Piazza. Between the diagonals and the vertical axes, the print establishes an axis mundi (a world pillar) placing the Piazza, the Rialto and the urban streets that connect them (the Merceria) at the ‘centre’ of the city, and the city at the centre of an ideal cosmology. The Venetians and visitors that knew Venice would be able from the symbolic geometry and the physical facts of the topography to perceive the pedestrian route between the two hubs as the urban spine of the city. Jacopo’s image translated the empirical city to a transcendental mythical city of imperial achievement and republican ideology. Being both factual and fictional, the print raises the fundamental problem of deconstructing Venice’s Myth into its constituents - spatial
relationships and ideology – in order to understand its internal conflicts. How did the symbolic instruments of Venetian identity relate to the city’s spatial geography, social and cultural institutions? This question is explored by looking at two filters: first the spatial organisation of the Piazza and the Basin in relation to the city as a whole; second, at popular myths local traditions and civic rituals.

The choice values of the pedestrian network of the city reveal that the Piazza and the Piazzetta are criss-crossed with lines, connecting them with the squares of the neighbouring islands. Two strong lines, one traveling through the Merceria, and the other through the Calle dei Specchierei connect the complex, through the campi of San Salvador and San Lio with the commercial district of Rialto (figure 2). The combined pedestrian-water structure shows a similar pattern, although emphasis in terms of choice values shifts from the pedestrian elements to the canal infrastructure (figure 2).

The distribution of the measure of integration in figure 3 shows that the Rialto, the Piazza and a group of streets connecting these two hubs define a deformed wheel that links the heart of the city with its periphery extending in opposite directions. This is a common characteristic in cities, easing movement from the outside to the central streets and squares, facilitating trade and large-scale communication (Hillier and Hanson, 1984). While the property of integration reveals the strength of San Marco and the Rialto in the context of the city as a whole, the measure of choice shows that the Piazza and the two squares on either side of the Rialto have the highest values in comparison to all other campi in the city. The Piazza and the Piazzetta are highly accessible spaces, channelling movement from everywhere to everywhere else, as well as attracting movement from every place to the heart of the urban complex.

How did Sansovino respond to these properties of the city? This is explored through the visibility structure of the Piazza complex separately from the organisation of the surrounding fabric. The results show that in Sansovino’s scheme visual integration spread from the space in front of the Basilica to the entire layout (figure 5). Improving the visual connections between the Piazza and the Piazzetta, Sansovino expressed the union of religious and political life. This union is also communicated through two strong diagonal links connecting the Palace and the Basilica with the western part of the Piazza, its more secular side. Sansovino’s efforts to unify existing elements into the new scheme therefore, demonstrate a concern for integration between the aesthetic treatment of buildings, such as the continuous loggia and the placement of archways at the intersection of important axes, and the urban fabric.
This is strikingly revealed when we look at the Piazza in the context of the neighbouring islands. A powerful axial link, clearly distinguished by strong red colour, emerges from the Merceria through the central archway of the Orologio, thrusting diagonally forward to the Columns of Justice. The line asserts the north-south pattern of integration that joins the Piazza and the Rialto (figure 4). The consonance between the properties of the Piazza and the properties of the city as a whole shows the strong role of the Piazza and this particular axial link across all scales of the analysis. The significance of this link in the life of the Venetians is evident in the fact that in the 15th century they felt the need to give a ceremonial entrance to the commercial thoroughfare by building the Orologio.

In Jacopo’s woodcut this axis has geometric definition (figure 4). In the Piazza it has architectural definition through significant buildings and their iconographic programme, such as the Orologio, the Loggeta, the Porta della Carta and the two Columns of Justice. Emerging from the collective unconscious efforts that built Venice over time, the Merceria line helped to articulate the self-conscious relationship between architecture, the city and the viewer. Sansovino seized the urban properties of Venice and used classical architecture to powerfully express the city-state and the Republic. It is this interweaving of the urban structure crafted by many hands with the architectural structure, made by fewer hands, that defines the intersection of Humanist architecture with the city and urban design.

5. STAGECRAFT: BRINGING THE IDEAL INTO THE URBAN FABRIC OF THE REAL

A look at the Piazetta from the water reveals the close relationship with the Tragic scene of Serlio (figure 6). Serlio interpreted the three typical scenes of antiquity described by Vitruvius as elaborate exercises of urban perspective: the Tragic scene which was defined by palace facades of elegant characteristics, corresponding to the administrative use of space; the Comic scene consisting of irregular buildings, related to the everyday use of space; and the Satyric scene associated with the disordered uncultivated nature. The correspondence of the Piazza with the Tragic scene is evident in Sansovino’s efforts to clear away the shacks of butchers, cheese and salami sellers who had infested the area (Howard 1975). Closely associated with this was a decree that eliminated the slaughtering of the pigs and bulls by the crowds during carnival, replacing popular elements with more noble entertainments such as comedies, ballets, and pageants (Muir, ibid.). The intention of the authorities was to magnify the Piazza for state ceremonies, elevating it from Comic scene - characterising the streets linking the Piazza with the Rialto - to Tragic setting.
The Tragic theatrical function of the Piazza is also evidenced in the concentration of many rituals in this space. In medieval Venice ritual was the result of popular mythopeoesis, and was organized by the parish islands. In the 16th century, with state intervention, parochial rituals were decreased in number, and the island communities were suppressed so that attention would turn to civic rituals in the Piazza San Marco.

Civic ritual acquired official organization by the state and became hierarchical – with the Doge at the centre, the confraternities and guilds marching at the front of the Doge and the patricians following behind him, reflecting in this way the hierarchical structure of society. Theatre, architecture and political administration coalesced at the expense of the anonymous spontaneous production of the city. The emergence of architecture as liberal art coincides with theatrical civic ritual and the official historiography by the Venetian Humanists who contributed to the Myth of Venice as the most serene Republic. From that moment architecture and the city were no longer part of the same continuum, developing along paths that remain paradoxically distinct as well as interrelated.

Figure 6 - Serlio Tragic scene (left); The Piazzetta seen through the water


Palladio’s churches in Venice’s southern islands were built at the end of the 16th century, completing through geometrical alignments and frontal relationships the transformation of the Piazza and the bay into an aquatic theatre (figure 8). In the Four Books of Architecture Palladio writes that temples should face important public buildings, rivers and watery expanses (1570). His church of San Giorgio Maggiore faces the Piazzetta and is struck by the extension of the Merceria line that links with the Rialto (figure 7). If the Piazzetta was the ‘eyes of the Republic’ the Rialto was its ‘viscera’ (Tafuri 1995). We encounter here de’ Barbari’s axis extending from the interior of the city to the island of San Giorgio and notionally beyond where the lagoon meets the Adriatic, uniting everyday places with cosmological relationships and sacred geography, such as the inside and outside, the city and the sea, commerce and the empire, civic identity and collective parochial identity, city-craft and statecraft, or the anonymous production of the city by many hands and the conscious appropriation of ritual by patricians that were exalting the state and the Republic.

In the festivity of the Redentore in 3 of May 1577 as well as in all the subsequent annual rituals of Christ the Saviour in the third Sunday of July, the Venetians cross the bay through a temporary causeway of boats that stretch from the Piazzetta to the Giudecca. Seen from distance across the water, churches in the early days of the Venetian archipelago would offer sure anchorage for sailors, under the protection of the parish saint. Founded on maritime enterprise, Venice’s islands had old associations with navigational practices, guided by churches that were sacralizing its waters through loci sancti. Toponymy bears witness to this process, as Venice’s campi are named after their saints, while portolan maps linking rose compasses with navigational lines must have expressed for early Venetians a water-borne network of sacred sites.
Palladio and his patrician mentors, such as Daniele Barbaro (1514-1570), were thinking according to cosmological references, seeking connections between ecclesiastical architecture, the city, mathematics and cosmological structures, a common in architectural theory at the time. Following Neoplatonic theories of cosmological harmony, they saw architecture and the city as representational diagrams of cosmological expression translated into civic integration. When Venice’s islands joined, the waterborne network of squares and churches was ritually connected through processions, transforming streets and canals into *viae sacrae*, as exemplified by the network of choice (Muir, ibid.). The geometric coordination of religious buildings in the Piazza and the Basin captures the grafting of navigational and ritual spatial networks of medieval Christian origin onto Republican ideology and Humanistic cosmology, as exemplified by Renaissance classical monuments and churches.

These ideas found expression in close relationship with theatre. Temporary theatrical structures such as the *Teatri del Mondo* (theatres of the world) alluded to the union between celestial and terrestrial spheres with representations of planets and zodiac circles in their ceilings. A few years before the construction of Palladio’s churches, in 1560, Alvise Cornaro proposed his plan for transforming the Basin to a theatre and ideal garden. His proposition included a floating Roman theatre, a fountain with water from the rivers of the Veneto and an island-hill with an open loggia at its summit. His theatre prefigures Palladio’s Teatro Olimpico and had its roots in the tradition of the *Teatri del Mondo*. Cornaro imagined it as a place of spectacle and as a spectacle in itself, explaining that all the elements of the project could be seen synchronically from the greatest theatre of the Serenissima, which was the Piazzetta (Tafuri, ibid.). The second project that had an influence on the to San Marco through the Merceria and from the Piazzetta).

Figure 7 - The Basin of San Marco, geometrical relationships and isovists in purple (from the entrance to San Marco through the Merceria and from the Piazzetta).
asin was Gulio Camillo’s theatre. In this work Camillo described a wooden structure constructed as a Vitruvian amphitheatre. The observer stood on the stage and looked at a semi-circular structure of seven tiers marked with images and boxes. The structure was intended to represent ‘the universe, expanding from First Causes through the stages of creation’, and enabling complete memory of all the knowledge that was available at the time (Cosgrove, 1993: 242).

Vitruvius’ Roman theatre consisted of four isosceles triangles centering on the orchestra (figure 10). Seated in the network of this spatial geometry, the audience was part of cosmological perspectival representation. The same principles were used in Teatro Olimpico by Palladio (figure 9). Vitruvius, Serlio, Cornaro and Camillo’s theatres came together in the scenographic treatment of the Piazza and the Basin, revealing conscious construction of the city as public theatre, and representational mythical world.

These projects have autonomous theoretical and aesthetic interest, but in this paper the emphasis is in explaining how they have influenced the view of architecture and the city as scenographic aesthetic phenomena, rather than as complex entities of evolutionary adaptation. The Venetian patricians and architects were operating in a different intellectual, socio-economic and political context. Yet, the theoretical heritage they left us remains unexamined in terms of the relationship of architecture and the city. The transformation of the Piazza and the Basin annexed the urban network as a field of popular mythology ritual geography and everyday practice, separating the aristocratic definition of the city as city-state from the collective formation of the city as everyday life. If architecture as liberal art was defined by conscious knowledge, it was equally defined by the elite mechanisms of the society it served. Both architecture and ritual became tools through which the city’s complexity was simplified, ordered and classified to project the image of a perfect society top-down.
7. CONCLUSION

In the squares, the canals and the alleys of Venice, the Venetians were celebrating their city as the foundational place of their society. The city of Venice was the outcome of evolutionary urban development, mythopoiesis, symbolism and ritual. Along with its gradual construction the city was also developing its history and mythological foundations based on ritual processions. Ritual was dramatizing the creation of Venice, uniting streets, architecture, myth and informal theatre in a coherent structure of space and place. The Venetian Humanists connected an inchoate collection of beliefs into official historiography writing about the political and mythological interpretation of the city, but did not describe the ritual processes, obviously knowing that people, immersed in the city customs since they were born did not need detailed descriptions (Zimmerman 1997). Having internalized the spatial and ritual structure of society, the Venetians had no need for verbal records. The space of the city was a matter of everyday practice and memory, rather than writing and speaking, which characterized the development of architecture as discipline separate from the artisanal traditions. Urban space was related to movement, theatrical performance and their sequence. Its significance was defined based on spatial practice and not specific instructions, such as go to this place, follow this route, pass through this place, or perform such and such activities and ritual actions (ibid.).

In the 16th century the city as spatial, ritual and mythological construction that follows from collective spontaneous processes was appropriated by official historiography architecture and civic ritual. It has remained since then in the blind spot of conscious design rooted in the schenographic aesthetic understanding of space that leaves the signature of an author (or a limited set of authors). Space and spatial practice do not have means for being represented, recorded and transcribed. What cannot be recorded cannot be transmitted, gradually leading to the rift between architecture and the city, representation and spatial practice (figure 10). Losing the capacity to unite the two realms, we are constantly missing the possibility to influence and enrich them through conscious comparative thought of the architectural kind. In response to the visions expressed in the Quito Papers, or research using space syntax, which equally separates architecture from the city and splits it into an aesthetic and social practice (Psarra 2009), the example of Venice explains that the values of informality, porosity and synchronicity can be attainable only when we grasp the need for a theory and a method for describing the relationship between architecture, design, urban planning and their history. We need to understand them not as static notions that are separate from each other, but as interrelated ones that are also fluid, shifting through time.
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MODALITY ENVIRONMENTS:
A Concept For Sustainability And Vitality In The Multi-Modal City

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ABSTRACT
This paper reviews an idea of vital local high-street places with their walking spaces and economies founded in interfaces between neighbourhood and city (between walking and public transport/bicycle movement infrastructures). It then extends this idea to higher scales, considering interfaces between city and region, which have already been theorised as ‘mobility environments’ (Bertolini & Dijst 2003) focusing on places and modal transfer points in new regional cities of high mobility. High-streets and mobility environments are both central places and our way of describing them suggests a new definition of central places as interfaces between normative (but also technically-infrastructurally supported) political spaces (neighbourhood, city and region). It also clarifies the role of scale in place theory and we will deal with this in a following paper. Here we introduce ideas of ‘modality places’ and ‘modality environments’. The ‘modality environment’ is concerned with areal and network transportation forms in whole fabrics and resulting conditions of sustainability and urbanity. Modality environments are understood in terms of transportation networks and the social and functional factors (like sustainability and urbanity) they produce. Modality environments are seen as lived environments built around movement infrastructure grids that distribute everyday urban functions. Ideally modality environments would be simple clear grids that distribute all or close to all the functions of everyday life so that a walking grid or a bicycle grid that gets adults to work, their children to school and includes shopping and recreation would be walking or bicycle modality environments. They would be expected to have high levels of direct visibility-legibility in the way urban elements present themselves to a mobile community. Modality environments would also include the central places (like high-streets or mobility environments like stations) at which people would transfer to other modality environments. We will use a notion of ‘movement culture’ to indicate the convergence of land uses and mobile communities mediated in information-rich networks. We are concerned first with how modality environments (for cycling or walking for example) may afford more sustainable lifestyles. We are concerned in addition with the ways they can be designed to include central places as zones of urbanity and vitality and as socially and culturally mixed centres. We start not with a principle of accessibility off from nodes in an extensive space but with the idea that particular social and political territories (communities and polities) are already articulations of distinct modality environments. We demonstrate using the case of the Amsterdam metropolitan area.
1. SOME BACKGROUND: WHY DOES SPACE SYNTAX WORK?

We have already argued (Read 2014) that the working of space syntax does not necessarily validate the official version of its theory and that explaining space syntax’s efficacy as a model of urban form and function in a different way, using a different theory, may open up also new insights into the nature and function of cities (O’Sullivan 2004). More generally, the model of science embedded in particular models may be inadequate to the task at hand and may lead us astray through embedded conceptualisations of time and space. We believe we are compelled to think historically about structure if we are to understand the ways physical and human geographies come together (Massey 1999).

We have proposed that the reason space syntax works is because there is a structure already historically embedded in the layouts of cities (Hillier 1999; Read 2005). This structure is a network, referred to as the supergrid, that in space syntax terms radically ‘shortens’ city-scale trajectories through the city. Total ‘distance’ through the city is minimised by this device and space syntax measures therefore reflect predominantly ‘distance’ from the ‘supergrid’ into neighbourhoods. In very broad terms, well-integrated areas are those with (locally) very close, transparent relationships between city (reflected in the supergrid) and neighbourhood (non-supergrid) spaces.

Figure 1 - Amsterdam: showing the supergrid. We see how neighbourhoods are made distinct (given their presence) not as bounded territories on a map but as a fine-grained network centred on a courser-grained network. Image: Jorge Gil
Space syntax thus reveals a characteristic structure in European industrial and other cities. But the structure exists before the rationale space syntax offers for movement structure and for other reasons than space syntax gives. It is not an emergent consequence of trips through the city (from everywhere to everywhere). It is first simply an intervention and a construction made in a certain time for quite clear strategic reasons: to distribute the major institutions, land uses, commerce, neighbourhoods and centres of cities and to carry the city-scale traffic between these elements (think of Haussmann's interventions for the remaking of Paris). It is secondly a 'technology of memory'; acting as a whole it is the externalised memory (Stiegler, 2006) and orientation map of the elements and centres of a city, as they are articulated around a material grid.

It is thirdly (and this is where our theory of place and centrality comes in) the line of interface between two grids, the other being the much finer street and block grid of the neighbourhood. This is an interface between different scaled and constructed grids but also between different scaled logics and definitions of community and emplacement (of the neighbourhood and the city in this case). It is lastly and as a consequence of the last, a centre of the lives and activities of people moving in and oriented by the neighbourhood grid.

A grid here is a distributor of elements and a medium of movement, at whatever scale, from a pedestrian street-block network to an industrial city supergrid and further (highways, railways and air transport systems). It is at the same time a medium of urban order and it constructs and is a condition of a polity and community. It is infrastructural, part of a huge, integrated technical adjunct to human existence that includes "cars, roads, municipal water supplies, sewers, telephones, railroads, weather forecasting, buildings, even computers in the majority of their uses [that] reside in a naturalised background, as ordinary and unremarkable to us as trees, daylight, and dirt" while it links "macro, meso, and micro scales of time, space, and social organisation ..." (Edwards 2003).

It works by distributing characteristic formative and identifying features of the community it contains (a village grid distributes a church, a school, a town hall, a market, a baker and a blacksmith; an industrial city supergrid distributes centres and neighbourhoods and cultural and political institutions like museums, libraries, churches and administrative buildings. It also distributes commerce pretty well continuously. This organisation and 'centring' of a polity on a grid has qualitative cultural and experiential consequences due to the way it interrelates and creates a complex compound of land uses and does this by making things visible and legible in movement.

We interpret space syntax not in terms of an analysis of access in a city or area therefore but in terms of a revealing of an historically built construction that is of its time. We understand urban structure to develop as new strategic interventions and constructs of relations between scales – those of the city and the region and the neighbourhood and suburb and the region – appear. A brief introduction to some of these changes will be included in the main text.

These constructs establish conditions of urban orientation, knowledge and experience. They found urban spatial cultures and qualities. They may be a source of the productivity of human societies and the way for urban designers to these qualities and productivities may be directly through an understanding of these forms-constructions and their workings.

We wish here to use and develop these insights to look at the issue of transportation and its division into modes from both historical and normative points of view. We are concerned with finding paths to sustainable transportation, which means paths to increasing pedestrian and cycling traffic and reducing dependence on the motorcar. We conclude that areas strongly adapted to pedestrian and cycling modes already exist in the central (historically industrial or pre-1930s) parts of (certainly European) cities. Normatively we propose that in order to create strong pedestrian and cycling zones we should learn from the success of historical centres and that part of the lesson is the structuring of life around grids that carry and represent in direct and visible ways all, or as many as possible, of the functions and elements of everyday life.
2. SOME THEORY – NETWORKS, PLACES AND SCALE, AND SUSTAINABILITY

We see this revision of space syntax theory as linking to a strongly materialist and earth-bound tendency in understanding human and social conditions. The notion of the Anthropocene draws earth and human histories as well as geological, biospheric, climatological and human worlds into the same orbit of discussion (Crutzen & Stoermer 2000). Peter Haff has added the Technosphere to the discussion as an objective reality of not just humans but also of geology, biosphere and climate (Haff 2014). This huge socio-technical, exosomatic apparatus is structured, following and developing Sloterdijk (2013), as a system of interiors and this historical structure (or better construct) to a very large extent constitutes our urban as well as human geographies (Read 2017).

The 'space' here is basically network space understood in a material and technical (and constructed) way, and 'interiority' refers to the inclusions of networks – as relating-including particular things and places – while 'exteriority' refers to their limits and exclusions and to a multiplicity of networks – as things and places are included in some networks and excluded in others. Networks here are infrastructures, concrete technical apparatus made in particular times to connect particular places together. These are already scaled, as opposed to the non-scalar abstractions of networks in some urbanisms and geographies.

In place of a metaphysical 'space' that is everywhere equal into which we insert static abstractions like scale and oppositions like urban-suburban – even things of unspecified and undetermined scale like ‘community’ – we have concrete spaces that have been already differentiated in their dynamic and historical compositions and relations and that support and specify places, scales, territories, urbanities and communities through the relations established. This may be seen as part of an historical process of making complex relational things like places distinct in the world that Derrida described as a process of différence (Derrida 1976). We would include urbanisation as one of these processes.

This technical-relational dimension of network and place is retheorised (Read 2014; Read 2017) and is summarised in its most relevant points here. Networks are discrete and to a degree autonomous in that they work as wholes through their ‘internal relations’. But they are never tabula rasa because they include historical places that pre-existed them. They at the same time (re)structure these places by including them (and by excluding others) and by transforming included places as a product of the ‘internal relations’ of included places with one another in the network. These discrete networks exist across the range of sub-planetary scales – as distinct scales that interrelate and overlap and often nest in one another. The resultant basic structures of places and scales tend to be quite consistent at least across continental and global regions (and to become more consistent with time).

The places that particular networks include together, are not arbitrary. They are selected according to a strategic logic of the network itself and its constructors. Strategies may be to connect neighbourhoods (horizontally) into a city or cities (horizontally) into a nation and pre-existing places will be selected to these ends. Places and their scales become regularised and formalised through their inclusions, revealing their significance and identities as political entities in their relations with other places. Neighbourhoods, national cities and world cities are all places of particular scales. They all include other scales as well however that are strategic to their existence as neighbourhoods, cities etc. and that define further their properties and qualities as places. A neighbourhood place has a (vertical) relation and serves as an interface with a specific city and it is this coupling that gives the neighbourhood its distinctive properties and qualities. Likewise a city has a (vertical) relation and serves as an interface with a nation through national networks or has a relation and serves as an interface with the globe through global networks.

All places have more than one network and no place has just one scale, though all of its scales will be consequences of networks it is part of. Places are always two (or more) -sided in that they may be seen as place-environments from the inside (inside a neighbourhood for example) while they may be seen as place-objects from the outside (from somewhere else in the city or the world for example). The place is necessarily also an interchange, a crossing point and
an interface between networks. This is the foundation of its centrality as a place. Centrality is therefore always also always multicentral; a global-national centre (like Schiphol Airport) or a national-city centre (like Amsterdam Central Station) or a city-neighbourhood centre (like the Ferdinand Bolstraat).

Place change will be a consequence of specific inclusion-exclusion and interface-interchange strategies and dynamics. Infrastructures become in this way a hugely important strategy for the design and roll-out of modern polities and societies (Hård & Misa 2008; Levin 2010; Van der Vleuten 2004; Read 2017). The places that become national cities, when railways are constructed for example, will in most cases be cities already, and the choices of which cities to include in main lines will be a charged and political affair. The choices for neighbourhoods to be connected into a tram network will be strategic and linked to local ambitions for places and overall political strategies for the city. At the other end of the scale, global and world cities are a select group of cities that themselves put effort and invest political capital in strategising to remain in or become part of the networks of global and world cities (Knox & Taylor 1995; Taylor & Derudder 2004).

The network technologies and their inter- and co-organisations to a very large extent themselves create the scales as well as the particular attributes of places in the network. Thus ‘scale’ is not just descriptive of places, it refers to particular constructions and configurations of networks and to the use to which people put places in acting in the world. Networks are at the same time implicit in this use; it is impossible to act at a city scale, or nationally, or globally without engaging a network of the appropriate scale. What other meaning can ‘scale’ have in relation to human geography? Power is therefore not just about a politics of territorial strategy and competition, it is also about the capacities network technologies, and the places formed in them, afford people when they have access to them.

The whole layered system is of organised ‘horizontal’ relations within networks complemented by organised ‘vertical’ relations between networks. This is rather different to network theory which does not differentiate between a network of neighbourhoods, a network of cities or a world city network, which sees networks exist simply against a background of a cartographic or geodetic surface where scale is not an intrinsic factor. In fact Marston et al. (2005) claim that scale does not exist in geography and Bruno Latour’s scales may be crossed without difficulty only when he discounts the difficulty of building them in the first place. The places involved in the activities above are however not simply location mapped by cartographic coordinates in a universal extension. These are places already particularised, identified and scaled by the particular concrete networks they have been built in or appropriated into. These places have further been developed and enriched through the activities the networks facilitate.

3. MODALITIES, ‘TOPOLOGIES’ AND CHANGE

We have previously called the resulting ‘horizontal’ technical-political constructs ‘technospaces’ (Read 2013) and the interfaces between ‘vertically’ related technospaces ‘technoplaces’ (Read 2017). We will rename technospaces here ‘modality environments’ and where appropriate technoplaces as ‘interchanges’ to discuss issues of multi-modal transport. Modality environments, as we have seen also carry the normative and political aspects of polities as well as the ‘communities’ and ‘cultures’ of these polities. But such a ‘topology’ exists most clearly and explicitly in modern transport networks and interchanges, making new places and cultures as a product of infrastructural change, and undermining and problematising or at least changing the previous setup.

The factor of scale here ties particular technical networks to social practices through differently scaled and sized networks of mobility – of walking, of cycling, of travelling by tram, or by train or car. What is important is that in the periods when these networks were made urban social practice was contained in these networks. Preindustrial communities used their feet and their lives were centred on and contained in walking-scaled modality environments, industrial communities use urban public transport and their lives are centred on and contained in public transport-scaled modality environments and post-industrial or suburban communities
use motorcars and their lives are centred on and contained in motorcar-scaled modality environments for example. Epochal changes have involved the wholesale shift of communities and even populations from one dominant transport mode to another connecting a whole different array of life factors together. But at the same time different modality environments, the highway system, an historical industrial 'supergrid' system and a pedestrian system, for example, may and do coexist alongside one another.

In public transport networks ‘horizontal’ connections are punctuated by stops (and stops are places on the network) and more significant stops will connect the whole system with another at a higher or lower scale (a tram interchange with a train system for example or in the case of TOD a transit interchange with a ‘pedestrian pocket’ (Kelbaugh 1989). Also train and bicycle, train and bus, train and tram, train and metro, car and bus etc. relations are organised in highly planned interchanges. But these are modern cases of what we argue is an historical and ‘generic’ process not limited to modern networks.

These modality environments relate back to their histories through the ways they are built over previous human-technical constructs so that neighbourhood networks may be adaptations of village networks for example or regional centres may be adaptations of neighbourhoods. Also they don’t always specify hard distinctions between transport modes (cars, bicycles and trams all use mid-scale ‘supergrid’ routes for example, but interestingly, all tend to the same speed).

Modern intercity networks will be built next to or be adaptations of older intercity networks and regional or suburban networks may be adaptations of older intercity networks. This gives us potentially more precise formalisations of the role of movement technologies in social-urban practices and the changes of these. It at the same time restores to history a central role in the structuring.

Sustainability is a relatively simple matter in the mobility discussion. It concerns the extent to which everyday movements are extended and transfer to non-sustainable modes like the car. We have potentially here a framework to discuss this in terms of a shift of dominant lifestyles from being centred on a modality environment like the supergrid to a high scale modality environment like the highway system.

4. EXTENDING THE ‘MOBILITY ENVIRONMENT’ CONCEPT

Modalities in the discussion above are linked loosely to particular networks. These networks are at the same time much more tightly related to scales and to the polities normatively linked to those scales – to neighbourhoods, cities, regions and so on. Some may object, saying there is no necessary reason why mobility networks should relate so strongly to polities. We will say this tends to be so historically and argue that the tighter link with scale is certainly sustainability related in that it refers back to times when daily movements were shorter and relates to a value ascribed to older historical structures: that one does not need to use ones car for a larger number of everyday journeys and activities. It suggests shorter distances in general between the different elements (home, school, work, shopping etc.) of everyday life. At the same time the integration of functions and movement with their visual aspects carries legibility and cultural consequences and we argue later there is a ‘normative tendency of modality places’ – with an integration of urban life and its visual aspects around lower speed grids.

Luca Bertolini has argued that mobilities today are threatening established social and political territories and places of belonging (Bertolini 2006). His idea of the ‘mobility environment’ was a response to the increasing mobility of people and their increasing independence of physical boundaries, focusing on places and modal transfer points in new regional cities of high mobility and aiming to describe better the effects and transformations of mobilities on regions (Bertolini & Dijst 2003; Bertolini et al. 2005). Mobility environments are “places where mobility flows interconnect—such as airports, railway stations, and also motorway service areas or urban squares and parks”. They “have the potential for granting the diversity and frequency of human contacts that are still essential for many urban activities” This is a concept to “help better articulate planning and design strategies that try to cope with the reality of an increasingly borderless urban system” (Bertolini & Dijst 2003). He saw the “need to link effectively the debate
about the transformation and expansion of infrastructure networks to the debate about the design of places and the more general debate about the cities we need and want, or ‘urbanity”’ (Bertolini 2006).

In this framework Bertolini is also dealing in modes and modal changes in a city of variable speeds and seeing centres as transportation interchanges. He has however no spatial mechanism for this, what he does is investigate the distributions and gradients of attributes over a universal extension and in a graph space that mixes ‘space’ and ‘place’ attributes. The discussion is based in a space as extension across which access is gained (against a ‘friction’ of distance). It is onto this surface that places and networks as well as bounded territories are inscribed and tensions set up by the goods, people, money and information moving in different modes and at different speeds over territorial bounds. This is sometimes presented as an irreducible tension between different conceptions of space and place (Castells 1999), while we argue that the territory does not sit between oppositional (metaphysical) conceptions of a global network and a bounded place but should be seen somewhat generically as places and centres of interchange between different networks – and that means between different scales, modes and speeds. We can see territories as more than the legalistic abstraction depicted on maps and show more explicitly how mobilities are, to quote Bertolini, “a central, structuring perspective on the development of cities” (Bertolini 2012).

What Bertolini says is true as far as it goes but, operating in metaphysical space and without a spatial mechanism, he can say little about how changes are happening or how distinctions in the urban field are operationalised. We believe the spaces involved in the changes should be intrinsic to the explanation of how changes occur. Our ‘articulated networks’ approach goes further than the modern transport interchanges the concept of the ‘mobility environment’ was designed to address to include a number of other articulations of networks of different scales and relate these to notions of ‘place’ and ‘centre’. Bertolini’s mobility environments remain for the most part a regional-scaled subset of this.

The modality environment approach ‘lifts’ us out of an insistent horizontality and offers spatial mechanisms for vitalities, centralities, urbanities, sustainabilities and capacities for mobility in modern regions and cities.
5. AMSTERDAM’S POST-WAR CHANGES

Societies are ‘scaling up’ in the changes that have occurred in European cities since the Second World War, and this occurs not in a generic extension but in specific new networks constructed with and incorporating new infrastructures and new mobility practices, while being at the same time constrained by the complex organisational and path dependent effects of new with old networks.

Social and functional lives that were previously lived in places and networks at the scale of the industrial city are now lived in places and networks at the scale of the region. People who used to live in an urban neighbourhood, shop on foot in the neighbourhood, send their kids to school by bike, and go to work by bike or by tram in the city, now live in a suburb, go shopping by car in an out of town centre, send their kids to school by bus or take them by car in another suburb and go to work by train or car in the city centre or in another city altogether. This ‘rescaling’ involves a relocation of lives, from being located on, and oriented by, neighbourhood and city grids to being located on, and oriented by, regional and city grids. This is not simply a relocation in Cartesian coordinates, this is a relocation to different modality environments – to new technospaces centring new configurations of urban life-elements. This also changes the very conditions of urban life – of the ‘urbanity’ Bertolini refers to.

Taking Amsterdam as an example, and moving on from our previous discussion of life on the supergrid, Amsterdam restarted its development after the hiatus of the 1930s Depression and the Second World War with a huge reconstruction programme lead in the first instance by the Marshall Plan which emphasised economic liberalisation and modernisation and the building of highways and the promotion of oil and automotive industries. It involved also a massive housing programme built on a very different pattern to that before the war and reflecting the growing influence of the motorcar and a ‘post-industrial’ job market and consumerism.

The Netherlands are reputed to have not had suburbs before the 1990s because of strict controls of the boundaries of cities. This is not however strictly true because ‘suburbs’, well connected to the new highways, were simply tucked into the edges of the existing cities. The pattern was that while the highways were being built a new network of accessways to those highways was being established to service the new housing. While this connected with the already built supergrid the new network was built not as a grid of streets but as a set of traffic arteries and not connected liberally and directly to the neighbourhood but minimally and often indirectly as a means of car access and traffic control. The new neighbourhoods were no longer centred on these roads but bounded by them. This new network was also clearly not another somewhat autonomous grid but reduced to a set of dedicated directional connectors to the ring road and highway network.

In the Netherlands these changes were countered energetically through the 1980s and 90s (Ligtermoet + Louwerse 1999) with a campaign for the re-adoption of cycling as a dominant mode of transport. The new roads got dedicated cycling paths; what they didn’t get back was the easy legibility and Jane Jacobs-like streets and community of the pre-war city. The new roads were formalised as ‘S-roads’ (highway to housing project connectors) and it is along these we find the new postwar development projects. The inner-city neighbourhood had been supplemented by a new form of ‘suburb in the city’ designed for efficient access to the ring and inner city areas were ‘regenerated’ by connecting them directly to the ring road.

The person or family that moves from city to suburbia moves from being centred by a grid (the supergrid) which facilitates a life lived (from home to work to school to shopping and entertainment) on a tram or bicycle and within a radius of approximately 5-10km, to being centred on a grid which facilitates a life lived in a car for the most part and within a radius of 50-100km. This is not to say there are no provisions for cycling in the new regional city because there are. Even so the whole shift from city to region has been premised on a scale of suburban living with both a practical and a cultural emphasis on the motorcar and longer distances to everyday life-elements. New centres have been built, very often mobility environments articulating regional and city networks, bringing suburbanites back into the inner city to shop or to work. But the fact is they arrive more often than not by car, and even if they don’t they
experience city networks as places to go to (as object-places) rather than as places to be in (as environment-places).

It is on this contrast we base our view of sustainability in the contemporary (particularly European) context. What this contrast also points to is the loss of a visible, legible ‘movement culture’ – an ‘urbanity’ – of the type we saw on the streets of the pre-war European city as we move away from the industrial city supergrid. At the same time we see a reduction of cycling in Amsterdam from 48% of all trips around the centre to 32% for the city as a whole. Cycling as default transport mode is much more a reality in the zone covered by the supergrid than in peripheries, even when the difference in actual accessibility of urban life-elements is hardly reduced. In the suburban areas beyond the city the figures reduce still more.

A viewpoint that assumes a universal extension will not easily understand this loss of urbanity and its necessary link to the supergrid and pedestrian grid. Today we still see this urbanity, but increasingly often in a car-accessed ‘regenerated’ form that forms an element in basically regional life patterns and tends to degenerate the streets with the increased car traffic.

6. A ‘NORMATIVE TENDENCY OF MODALITY PLACES’ AND SOME STRATEGIES FOR MODALITY PLACES

This discussion shifts the sustainability and urbanity problematics. Urbanity has a strong ‘cultural’ dimension, tied historically to networks and their centrality and community factors, and it tends to be under threat in the new regional conditions. Sustainability is about reducing travel distances and especially about moving to slow modes of transport that do not use fossil fuel energy. What the discussion indicates is that sustainability, like urbanity, is not something present in potential just anywhere in an unlimited extension, but tends to be produced in the same city grid-neighbourhood grid historical pattern.

The ‘pedestrian pocket’ idea (Kelbaugh 1989) is a relatively simple interchange between transit and pedestrian networks that can be extended with an overlapping bicycle network. The similarities between this and the industrial city (supergrid) pattern suggests there is potential here for creating sustainable centres with urbanity. Another possible strategy for creating modality places away from historical central areas looks to create a convergence of structures of land use and their simultaneous legibility around a transparent movement grid in interactive and participatory ways. An online interactive tool that represents the bicycle network and the land uses it connects, performs some simple analytical processes related to network-land use integration, network transparency and distance, can (eventually) be used as a handy route-finder, and engage the public in altering and evolving the network while using the tool. The engagement of the public may further encourage the take up of the bicycle as default transportation mode. We want to provide controlled options to change network and/or land use in realistic ways to get better results. The collected results of these engagements could then be fed into meetings between users and transport and land use planners to ‘evolve’ a better bicycle network over time. The ambition is to evolve the network and land use integration continuously and incrementally and in a interactive and participatory way, to create a radically higher integration of network and land use (to the point the network becomes information-rich and ‘intelligent’).

The bulk of new development tends still to be attached to the historic cities but connected away from these centres to the highways rather than towards them through the supergrid. Traffic planning after the mid-1980s tried to minimise car use and this was the period – through to the 2000s – when efforts were made to concentrate development in transport interchanges (mobility environments). Railway stations in particular were sites for the largest number of new projects. Even greenfield (Vinex) housing would often include new public transport. It was this development phase that Bertolini’s work addressed. Today’s (overheated?) real-estate demand and activity has meant that transport development has fallen behind housing development and sites along the S-roads are again being exploited, with the expectation these will be attractive to car users. The form of new development has also changed with a lot more high-rise being built and new shopping and other facilities being ‘mall-like’ or ‘centre-like’ and not related to...
the street. This tendency combines with another of rising rents, which means that many of the small shops that relied on a street relationship are being priced out.

We see the possibility of hybrid approaches and would like to position this modality environment approach to address these changes by making on-going use of the qualities of supergrid street structures even while new forms of development are being pursued.

Figure 3 - New development sites in Amsterdam. All are linked strongly to the ring road. Image: dRO Amsterdam

7. CONCLUSIONS

Problems emerge with the ‘scientific’ abstractions of extensive space embedded in our modes of analysis. Such a uniform generic space implies uniform generic potentials for effects such as sustainability and urbanity. There are clear indications such potentials do not exist in this way and our explorations need to take on space itself (which must mean the space we have constructed) and attempt to model the sorts of material complexities that we have constructed and their consequences. Our ‘projects’ of ‘modernity’ have each built on the past to construct their own and new sets of metageographical elements and shaped particular modes of urbanisation. Specific spaces are constructed at different historical moments – we see the construction of a new regional space after the Second World War for example – and the switch of dominant processes from an older urban to a new regional space can only be understood in historical and spatial context. Any attempt to unify interpretations of spatial forms across such transitions will risk missing the point. Sustainability questions must be assessed in these historical and spatial contexts and in relation to the whole new relations of urban life that new spaces may engender.
REFERENCES


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PEDESTRIAN MUGGING IN DIFFERENT PERIODS OF THE DAY AND SEGMENTS ATTRIBUTES IN MOST CENTRAL BOROUGHS OF PORTO ALEGRE

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ABSTRACT
This paper investigates the occurrence of pedestrian mugging in different periods of the day (morning, afternoon, night and dawn) and their relationship with physical-spatial attributes of segments in 22 most central boroughs of Porto Alegre, including: segment length, connectivity, integration and choice, physical and visual connections, physical and visual barriers, lampposts, number of garage doors, types of building uses, and the uses during each of the four periods of the day on ground floors. In addition to the period of the day, other temporal attributes are considered, such as day of week, month and year in which the pedestrian mugging occurred. The 22 boroughs in the most central area of Porto Alegre were selected due to the highest concentration of crime in the streets, and to the fact that they are the most consolidated and dense urban areas, enabling the identification of the physical-spatial attributes of the segments. The pedestrian mugging occurrences were collected through digital platform “Where I was robbed” (www.ondefuiroubado.com.br) and cover the period from 01/01/12 to 31/03/16, totalizing 4 years and 3 months. The information obtained was recorded in the Quantum GIS program, based on a satellite image of the region and related to a segment map, generated by Depthmap. Segments attributes such as segment length, connectivity, integration and local choice were quantified by segments map analysis in Depthmap for the whole region covered by the 22 boroughs. The following segments attributes were identified and quantified via Google Street View for 30 segments with no pedestrian mugging in any of the four periods of the day and for 10 segments with most pedestrian mugging in each period (28 different segments since 12 segments were selected for more than one period): functional connections (number of accesses); visual connections, physical and visual barriers, lampposts; and garage doors. Types of building uses (residential, commerce/services and mixed use), and the uses during each of the four periods of the day on ground floors (the existence or not of residential, services or commercial activities) were identified through a map of uses elaborated by the City Council and checked via Google Street View. In addition, statistical analyses were performed in SPSS/PC program. The results show, for example, the tendency of pedestrian mugging to occur in the segments with lower visual and physical permeability and with greater length. Moreover, pedestrian mugging occurs with greater intensity in the Centro Borough and its immediate vicinity, mainly during the night, followed by the afternoon period.
KEYWORDS
Pedestrian mugging, segments attributes, street crime

1. INTRODUCTION
The importance of physical variables in preventing or reducing the possibilities of crime, including pedestrian mugging, has been established in studies carried out in distinct cities of different countries (Poyner and Webb, 1991; Voordt and Wegen, 1993; Hillier and Shu, 2000; Hillier and Sahbaz, 2005; Shu, 2009; van Nes and López, 2010; Hillier and Sahbaz, 2012). However, this is a complex subject where many physical variables are involved and interrelated, apart from other aspects, such as social, economic, and political ones, that may influence the occurrence of crime (Caldeira, 2000; Zaluar, 2002).

Although the relationship between physical variables (such as global and local integration) and the occurrence of crime has been dealt with by some studies, no conclusive evidence seems to have been produced. In this respect, it has been mentioned the scarcity of spatial analysis researches that focus on street robbery (Chiaradia et al., 2009). Moreover, different approaches regarding types of crimes and periods of the day when crime occurs have been considered in distinct studies, with some making a distinction between periods of crime occurrence and types of variables involved (i.e., Monteiro and Iannicelli, 2009). Additionally, it is not clear, for example, what is an acceptable level of physical and visual connections between the buildings and the street in order to make the streets safer.

It follows that there is a need to deepen the knowledge about the relationship between pedestrian mugging in different periods of the day and segments attributes. Therefore, this paper investigates the occurrence of pedestrian mugging in different periods of the day (morning, afternoon, night and dawn) and their relationship with physical-spatial attributes of segments in 22 most central boroughs of Porto Alegre, including: segment length, connectivity, integration and choice, physical and visual connections, physical and visual barriers, lampposts, number of garage doors, types of building uses, and the uses during each of the four periods of the day on ground floors. In addition to the period of the day, other temporal attributes are considered, such as day of week, month and year in which the pedestrian mugging occurred.

2. DATASETS AND METHODS
The 22 boroughs in the most central area of Porto Alegre (Figure 1) were selected due to the highest concentration of crime in the streets, and to the fact that they are the most consolidated and dense urban areas, enabling the identification of the physical-spatial attributes of the segments.
Data regarding pedestrian mugging occurrences were collected from 01/01/12 to 31/03/16, totaling 4 years and 3 months, through the digital platform “Where I was robbed” (www.ondefuiroubado.com.br) which is an app that allows the victim to mark on a city map the exact spot/address (street name and the closest building number) where the mugging occurred and fill in details like time, date, stolen items and a small description of the mugging. Therefore, it was necessary to be aware of the existence of the platform and to have access to the internet in order to register such crime, which might have had some effect on the victim type that registered the occurrence, for example, favoring such registration by students and workers of the Federal University of Rio Grande do Sul (UFRGS) that is located nearby many segments with most pedestrian mugging. Then, to avoid distortion (for example, in having segments from regions not used by students), the selection of segments with no pedestrian mugging was made considering a maximum distance of three steps of depth from a segment with most pedestrian mugging. The information obtained was recorded in the Quantum GIS program, based on a satellite image of the region and related to a segment map, generated by Depthmap. Segments’ attributes such as segment length, connectivity, global (Figure 2) and local integration and global and local choice were quantified by segments map analysis in Depthmap for the whole region covered by the 22 boroughs.
The following attributes were identified and quantified via Google Street View for 30 segments with no pedestrian mugging in any of the four periods of the day (Figure 3) and for 10 segments with most pedestrian mugging (varying from 2 to 10 mugging in a segment) in each period (Figures 4, 5, 6 and 7; 28 different segments, since 12 segments were selected for more than one period) in a total of 58 segments: functional connections (number of accesses); visual connections, physical and visual barriers, lampposts, and garage doors. Types of building uses (residential, commerce/services and mixed use), and the uses during each of the four periods of the day on ground floors (the existence or not of residential, services or commercial activity) were identified through a map of uses elaborated by the City Council and checked via Google Street View.
Figure 4 - 10 segments with most pedestrian mugging in the morning period
Note: orange dots = pedestrian mugging in the morning period.

Figure 5 - 10 segments with most pedestrian mugging in the afternoon period
Note: green dots = pedestrian mugging in the afternoon period.
Proceedings of the 11th Space Syntax Symposium

PEDESTRIAN MUGGING IN DIFFERENT PERIODS OF THE DAY AND SEGMENTS ATTRIBUTES IN MOST CENTRAL BOROUGHS OF PORTO ALEGRE

Figure 6 - 10 segments with most pedestrian mugging in the night period
Note: pink dots = pedestrian muggig in the night period.

Figure 7 - 10 segments with most pedestrian mugging in the dawn period
Note: blue dots = pedestrian muggig in the dawn period.
To enable comparison between segments, a rate was calculated for each attribute. Physical connection rates were obtained by dividing the total number of physical connections (doors that allow a person to access a building from the street) in both sides of the street segment (i.e. 58 accesses) by the double of the segment length (i.e. 274.11 m x 2 = 548.22 m), which, in this example, results in a physical connection rate of 0.106. This means that there is access to a building every 9.45 meters in the total length of both sides of this segment (548.22 m / 58 accesses). Visual connection rates were calculated by dividing the total length (in meters) of visual connections (windows and glass doors that allow a person inside the building to look at the street) in both sides of the street (i.e. 71 m) by the double of the segment length (i.e. 274.11 m x 2 = 548.22 m), which, in this example, results in a visual connection rate of 0.130. This means that only 13% of the total of 548.22 m are visually connected to the public open spaces of streets. Physical and visual barriers (such as walls) rates were generated by dividing the extent (in meters) of such barriers in both sides of the segment by twice the segment length. Lampposts rates were generated by dividing the number of lampposts in both sides of the segment by the segment length. Garage doors rates were calculated dividing the extent of such doors (in meters) in both sides of the segment by the double of the segment length. Rates of residential, commercial/services and mixed use buildings were generated dividing the number of each of these buildings types in both sides of the segment by twice the segment length. Rates of residential, services and commercial activities on ground floor of buildings facing the streets were calculated by dividing the quantity of each of these types of activities on both sides of the street segment by double of the segment length. Therefore, with exception of lampposts rate, which is an attribute of the segment and not of each of its sides or interfaces, variables rates are divided by double of the segment length because the attributes considered belong to each of the two segment sides, more precisely reflecting the relationship between the characteristics of the two segment interfaces and the length of these interfaces. In addition, statistical analyzes were performed in SPSS/PC program, correlating (Spearman correlation test) pedestrian muggings in each of four periods of the day with segments attributes.

3. RESULTS

Most pedestrian mugging in the 28 selected segments, from 2012 to 2016, tends to occur during the night period (55) followed by the afternoon (43), the dawn (25) and the morning (24) period, which emerges as the safest period to walk on the streets (Figure 8). Regarding day of the week, most pedestrian mugging occurred on Wednesdays (26), closely followed by Saturdays (25), Thursdays (24) and Fridays (23). The day with the smallest number of pedestrian mugging occurrences is Sunday (23), followed by Monday (18) and Tuesday (18). The largest amount of pedestrian mugging occurred on September (19) and in June (18) and the least amount occurred in December (8), followed by January (9), February (10), and May, October and November (11).

The percentage of segments with length above 150m is clearly greater in the segments with most pedestrian mugging (varying from 40% in the night to 60% in the afternoon and in the dawn period), regardless of the period of the day, than in the segments with no pedestrian mugging in any period of day (13.33%). Regarding segment connectivity, values do not reveal any major differences either between periods of the day for the segments with most pedestrian mugging or for the segments with no pedestrian mugging in any period of the day.
Consider the global integration values of all 30 segments without pedestrian mugging in any period of the day and of all segments with most pedestrian mugging in any of the four periods of the day (10 segments in each period in a total of 28, since 12 of these segments are repeated in different periods of the day), it is revealed that: the percentage of segments with the highest values is much smaller in the segments with no pedestrian mugging in any period of the day (20%) than in the segments with most pedestrian mugging in the morning (50%), in the afternoon (40%), and in the night (60%), disregarding the dawn period since integration values are not really useful during dawn, when differences in movement of people and vehicles during the other three periods tend to significantly diminish or to disappear. Moreover, 30% of the 30 segments with no pedestrian mugging have the lowest global integration values, while no segment with most pedestrian mugging in the morning, afternoon and in the night is in this group. Therefore, pedestrian mugging tends to occur in the segments with higher global integration values, as also evidenced by the highest and lowest global integration values and by the mean of global integration values of all segments in each of the five groups of segments (Table 1).

Table 1 - Global e local integration
Regarding local integration, most segments with no pedestrian mugging (76.76%) and with pedestrian mugging in the morning (70%) have the lowest values, also evidenced by the mean of local integration values of all segments in each of these two groups of segments (Table 1). Hence, there is no clear indication about the effect of local integration values on the occurrence of pedestrian mugging, what is also shown by the local integration values in the segments with most pedestrian mugging in the periods of afternoon and night.

<table>
<thead>
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<th>Table 2 - Global e local choice</th>
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<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>Highest values</td>
</tr>
<tr>
<td>(275,866 - 276,176)</td>
</tr>
<tr>
<td>Medium values</td>
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<tr>
<td>(1,088,743 - 2,761,768)</td>
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<tr>
<td>Lowest values</td>
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<td>(1,088,743 - 2,761,768)</td>
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Global choice analysis shows that almost the totality of segments with no pedestrian mugging (93.33%) has the lowest values (Table 2). However, the majority of segments with most pedestrian mugging in the morning (60%), in the afternoon (70%) and in the night (60%) also have the lowest global choice values. The dawn period has been disregarded since route choice values are not really useful during dawn, when differences in movement of people and vehicles during the other three periods tend to significantly diminish or to disappear. Hence, there are no clear indications about the effect of global choice on pedestrian mugging. Local choice analysis reveals that the totality or the clear majority of segments, either with or without pedestrian mugging have the lowest local choice values (Table 2). Nonetheless, pedestrian mugging in the afternoon was found to rise as local choice increased, as revealed by the positive correlation (Spearman correlation, coef. = .392, sig. = .032) between these two variables. Physical connections rates analysis reveals that while 56.67% of segments with no pedestrian mugging have high or very high physical connections rates, the totality of segments with most pedestrian mugging in the morning and in the afternoon, and 90% of the segments with most pedestrian mugging in the night have low or very low physical connections rates, disregarding the dawn period due to inexistant or almost inexistent access to buildings from the streets (Table 3). Therefore, in any of the three periods of the day, pedestrian mugging fundamentally occurs in segments with a physical connection rate not greater than 0.077 (means an access to a building every 13 meters or more, in case they were evenly distributed), and the majority of this type of crime occurs in segments with physical connection rates not greater than 0.038 (means an access to a building every 26 meters or more, in case they were evenly distributed), in any of the three periods of the day considered (Table 3). It follows that the number of physical connections between the buildings and the street in a segment is a strong indicator of pedestrian mugging in such segment. Nonetheless, although these data reveals the number of access to buildings in the segments, they do not reveal the location of such accesses, if they are close together, equally distributed in both sides of the street, or else, what is not part of the objectives of this research.
Although the majority (56.67%) of segments with no pedestrian mugging have low or very low visual connections rates (Table 3) between the buildings and the streets, the totality of segments with pedestrian mugging in the morning, in the afternoon and in the night have low or very low visual connection rates, disregarding the dawn period due to inexistent or almost inexistent visual supervision of streets by people inside the buildings. Therefore, pedestrian mugging occurs in segments where no more than 19% (rate of 0.194) of their total length (both sides of the street defined by the segment) is visually connected. Moreover, the totality of pedestrian mugging in the afternoon, and almost the totality (90%) in the morning and in the night occurred in segments where the visual connections between the buildings and the street is not greater than 10% (rate of 0.097) of the total segment length (both sides). Therefore, visual connection rates emerge as an important indicator of pedestrian mugging during the morning, afternoon and night periods. Moreover, pedestrian mugging in the afternoon period was found to be negatively correlated with visual connection rates (Spearman correlation, coef. = -.426, sig. = .019) confirming that pedestrian mugging increases as these rates decrease. Nonetheless, these results do not inform the location and distribution of the visual connections along both sides of the segment, which is not the objective of this research.

Garage door rates analysis shows that the number of garage doors in a segment did not emerge as a facilitator of pedestrian mugging, in any of the three periods considered. The totality of pedestrian mugging during the night and almost the totality during the dawn period (80%) occurred in the segments with low (0.044 – 0.069) or very low (0.017 – 0.043) lamppost rates, and no pedestrian mugging in the dawn period occurred in the segments with very high or high lamppost rates. Hence, these findings reveal the importance of well-lit streets in order to prevent or diminish the occurrence of crime in public open spaces during periods without natural light. The totality of segments with most pedestrian mugging in the morning, and almost the totality of those segments with most pedestrian mugging in the afternoon (90%) and in the night (80%) have very low rates of physical and visual barriers (0.000 – 0.100). Therefore, physical and visual

Table 3 - Physical and visual connection rates
barriers (such as walls) in the streets are not found to be specific facilitators of pedestrian mugging in these three periods of the day, disregarding the dawn period when these barriers do not play a role in blocking the visual supervision of the streets from the buildings.

Mixed use building rates analysis reveals that the clear majority of segments with most pedestrian mugging in the morning (80%), in the afternoon (80%) and in the night (70%) have very low mixed use building rates (0.000 – 0.009). Additionally, pedestrian mugging did not occur in segments with very high rates (0.037 – 0.046) and almost did not occur in segments with high rates (0.028 – 0.036) of mixed use buildings in any of the three periods of the day. On the other hand, 43.34% of the segments with no pedestrian mugging have very high or high rates of mixed use buildings while only 16.6% of these segments have very low mixed use building rates (0.000 – 0.009). Consequently, the existence of mixed use buildings in a street tend to have a positive effect in reducing pedestrian mugging, what is also evidenced by the clearly higher total mean rate (0.025) in the segments with no pedestrian mugging than in the segments with most pedestrian mugging in different periods of the day. The analysis of residential use buildings shows that all segments with most pedestrian mugging in the morning and in the afternoon and 90% of segments with most pedestrian mugging in the night have very low rates (0.000 – 0.020) of residential use buildings, while 53.33% of segments with no pedestrian mugging have the same rates. Therefore, pedestrian mugging in these periods of the day is made easier in streets with very low rates of residential use buildings. This is supported by the fact that pedestrian mugging in the morning and in the afternoon were found to increase as the rate of residential use buildings decreased, according to the negative correlation (respectively: Spearman correlation, coef. = -.422, sig. = .020; Spearman correlation, coef. = -.493, sig. = .006) between pedestrian mugging in each of this two periods and rate of residential use buildings.

Regarding the existence of buildings with commercial/services use in the segment, 80% of pedestrian mugging in the morning, 100% in the afternoon, and 70% in the night period occurred in segments with very low rates (0.000 – 0.016) of buildings with commercial/services use. Therefore, the occurrence of pedestrian mugging tends to concentrate in the streets segments where rates of buildings with commercial/services use are very low, that is, where there is an access to a building with commercial/services use every 62.5m or more. Considering the existence of residential activities on ground floors facing the streets, it is revealed that 100% of segments with most pedestrian mugging in each of the four periods of the day, have low rates of ground floor residential activities (0.000 – 0.023), which means an access to a ground floor with residential activity every 43.5m or more. As a result, the existence of residential activities on ground floors of buildings facing the streets every 43m or less in average tends to discourage the occurrence of pedestrian mugging. This is corroborated by the negative correlation (Spearman correlation, coef. = -.617, sig. = .000) between pedestrian mugging in the afternoon and the rate of residential activities at ground floor during afternoon.

Concerning the existence of service activities on ground floor of buildings facing the streets, 100% of the segments with most pedestrian mugging in any period of the day have low rates (0.000 – 0.010) of service activities on ground floors, which means an access to a ground floor with service activity every 100 m or more. Therefore, the existence of some service activities on ground floors of buildings in a mean distance smaller than a 100m in a certain street tends to reduce the occurrence of pedestrian mugging. This is supported by the negative correlation (Spearman correlation, coef. = -.427, sig. = .019) between pedestrian mugging in the afternoon and the rate of service activities at ground floor during afternoon. On the other hand, pedestrian mugging in the night was found to be positively correlated (Spearman correlation, coef. = .447, sig. = .013) with rate of service activities at ground floor during the night.

The analysis carried out on the existence of commercial activities on ground floors of buildings facing the streets reveals that 100% of the segments with most pedestrian mugging in any period of the day have low rates (0.000 – 0.014) of commercial activities on ground floors, which means an access to a ground floor with commercial activity every 24.4 m or more. Hence, the existence of commercial activities on ground floors of buildings facing the streets each 24m or less in average tends to discourage the occurrence of pedestrian mugging.
4. CONCLUSIONS

The most dangerous time period for pedestrian mugging is the night, followed by the afternoon, while the morning is the least dangerous to walk on the streets considered in this study. Wednesday, closely followed by Saturday, Thursday and Friday were found to be the most unsafe days, while Sunday was found to be least unsafe, followed by Monday and Tuesday. September, closely followed by June, were found to be the most risky months, while December, followed by January, February, May, October and November were found to be the least risky months to walk on the streets, what suggest a tendency for warmer months, when there is more people walking on the streets, to be less unsafe.

The tendency for pedestrian mugging to be more intense in longer segments has been confirmed in this study, mainly in segments longer than 150m. On the other hand, segment connectivity was not found to have an impact on pedestrian mugging and so, is in line with the fact that ‘...segment connectivity does not, as commonly believed, predict movement.’ (Hillier and Sahbaz 2012, p.135). Contrary to some studies, where houses located in globally integrated areas tended to be less vulnerable than those situated in globally segregated areas (Shu, 2009), pedestrian mugging tends to occur in the segments with higher global integration values, what is supported by higher numbers of pedestrian mugging during the night in segments with higher global integration values (Reis et al, 2015). Regarding local integration and global choice values, no clear effect on the occurrence of pedestrian mugging was found, differently from other study (Reis et al, 2015) where higher local integration values were related to a decrease in pedestrian mugging during the night and global choice was the only variable to be related to a reduction in pedestrian mugging during the morning. The fact that segments with most pedestrian mugging tend to have the lowest local choice values may reveal the effect of this variable, although segments with no pedestrian mugging also tend to have the lowest values. Nonetheless, pedestrian mugging in the afternoon was found to rise with the increase of local choice values. Additionally, other research findings (Reis et al, 2015) revealed that higher local choice values were related to an increase in pedestrian mugging during the night period.

The number of physical connections between the buildings and the street in a segment is a strong indicator of pedestrian mugging in such segment (in the morning, afternoon and in the night period), and accesses to buildings should exist, if equally distributed in both sides of a street segment, at distances less than 13 meters in order to minimize the occurrence of pedestrian mugging. This is supported by other results where a reduction in pedestrian mugging during the night was related to an increase in the rate of physical connections in a segment (Reis et al, 2015). Visual connection between the buildings and the streets was also found to be an important indicator of pedestrian mugging during the morning, afternoon and night periods, indicating that this type of crime tends to be reduced when more than 15% of the total length of both sides of the street segment is visually connected. The number of garage doors and existence of physical and visual barriers (such as walls) in a street segment were not found to be specific facilitators of pedestrian mugging in the three periods of the day, with an exception that pedestrian mugging tend to rise in the morning period as physical and visual barriers increase. On the other hand, decrease in pedestrian mugging during the night and the dawn period is related to a better lit street, showing that a lamppost at distances smaller than 14.5m in a street segment is likely to contribute to reduce pedestrian mugging. This result is supported by the positive effect of poles with street lighting on reducing pedestrian mugging during the dawn, in another investigation (Reis et al, 2015).

The existence of mixed use buildings in a street segment tend to have a positive effect in reducing pedestrian mugging, in any of the three periods of the day, with a mean distance equal or smaller than 59m between such buildings, in both sides of a segment, having a tendency to decrease the occurrence of pedestrian mugging. Pedestrian mugging in the morning, afternoon and in the night is made easier in street segments with very low rates of residential use buildings, which means that a residential building at mean distances smaller than 50m in the total segment length is likely to favour a reduction in this type of street crime. This is supported by a decrease of pedestrian mugging in the morning and in the afternoon as the rate of residential use buildings increases. Moreover, an access to a building with commercial/
services use at a mean distance smaller than 62.5m has a tendency to reduce the occurrence of pedestrian mugging. The existence of residential activities on ground floors of buildings facing the streets each 43m or less in average tends to discourage the occurrence of pedestrian mugging. This is corroborated by a decrease in pedestrian mugging in the afternoon as the rate of residential activities at ground floor during afternoon increases.

Additionally, the existence of service activities on ground floors in a mean distance smaller than 100m was found to reduce the occurrence of pedestrian mugging. This is supported by a decrease in pedestrian mugging in the afternoon as the rate of service activities at ground floor during afternoon increases. Nonetheless, pedestrian mugging in the night was found to increase with an increase in the rate of service activities at ground floor during the night. This may happen due to the fact that service activities during the night are not enough to generate intense presence of people and so, users are not protected by the co-presence in these street segments. Moreover, the existence of commercial activities on ground floors of buildings facing the streets each 24m or less in average tends to discourage the occurrence of pedestrian mugging.

Therefore the investigation carried out regarding pedestrian mugging in different periods of the day and their relationship with physical-spatial attributes of segments in most central boroughs of Porto Alegre offers more detailed information and may contribute to the knowledge about the relationship between pedestrian mugging and urban design characteristics.
REFERENCES


#107
ENHANCING CITY URBAN PLANNING PROCESS THROUGH INTEGRATING GIS WITH SPACE SYNTAX SIMULATION TOOL

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ABSTRACT
Planning models and simulations support tools are considered to be an awareness-raising process in the strategic planning and design, as the aid of spatial models that integrate urban form with soci-economic data, can open up a bright spectrum of opportunities and insights that were not evident before. Emphasizing on the relationship between space and the spatial structure that are considered to be the fundamental concept of urbanism. This paper is concerned by discussing, and evaluating the design proposal of Airport Lake (El Matter lake) in Alexandria, Egypt, with the aid of an evidence based model. This adopted methodology integrates Geographic Information Systems (GIS) and Space Syntax into a single model. The model is based on analysing current land use densities, distribution, socio economic variables and network spatial configuration analysis of city, in order to predict the likely outcomes of the proposal on Alexandria’s urban life.

The model is tested on Airport lake area, using information collected from census data and General organization of physical planning. It is considered to be one of important areas in Alexandria city, due to its location adjacency to Alexandria city centre and also, it is characterized with multiple attracting elements that play main and important role in the urban and economic development in the strategic development scheme. Based on the development strategy of airport lake area and its surroundings in order to make good use of the area, whether on a touristic and residential aspects and to organize and control urban development. The adopted methodology will test the proposed design to achieve compatibility between the detailed plan as on the level of strategic design, and on general outline of the city as a higher level.

Thus, the developed model will bring together all the current available data into one practical, mappable, measurable and quantitative data produced by GIS, combined with qualitative analysis of the spatial configuration of the proposed area with the city as a whole produced by space syntax, then using Geographically weighted regression (GWR) to correlate different layers to each other. The model revealed important challenges whether on the local level of proposed area or on the level of Alexandria city development that could be used by stakeholders and the local authorities in decision making process, and assisting the quality of design, evaluating the possible policies and interventions in the light of the goals set out in Alexandria’s comprehensive city plan.

KEYWORDS
Strategic Design, Urban Form, Soci-Economic Variables, Geographic Information System, Spatial Configuration Analysis.
1. INTRODUCTION

Planning models and simulations support an awareness-raising process, as carrying out strategic planning and design with the support of spatial models that could integrate urban form with socio-economic data, can open up a bright spectrum of opportunities and insights that were not evident before. The research aims to fill in the gap and provide a framework to inform the limited physical interventions by relating different layers of analysis and design, to enhance urban design process of the city. Thus, the general approach in this study follows a process that includes four major elements:

1. A detailed spatial analysis method to select, refine the urban design structure of the city
2. Supporting model that studies and analyses the existing and possible situations
3. A review of the overarching proposed guidelines and strategies
4. Provide urban design development recommendations.

In this context, a hypothesis was proposed that integrate GIS based approaches with Space Syntax, to allow the creation of a composite model that integrate different layer for analysis, that enrich the results whether on the local level, or on the analysis of spatial configuration of city network. In order to, base the design on more layers of evidence model that describes and interprets the relationship between socio-economic variables and spatial characterizations of the urban agglomerations. a multi-criterion GIS method has been developed which takes into consideration different spatial factors and a set of socio-economic data. then using Geographically weighted regression(GWR) to correlate different layers to each other, it is a baseline guide for decision making and assisting the process of design. Moreover, The GIS tool can provide analysis of individual quantitative attributes of a selected layer, mapping the values using simplified symbology settings, displaying essential descriptive statistics, and plotting basic interactive charts, moreover can compare between different layers together. While, the Space syntax theory addresses the relationship be-tween physical elements of a city known as, configuration, its social activity and the pattern of utilization. This method is based on analyzing the current land use densities, distribution, socio economic variables and network spatial configuration analysis of city, taking into consideration the cause and effect between spatial and socio-economic factors, as it considers space and the spatial structure as the fundamental concept of urbanism.

To enhance city planning, the needs of city must be fulfilled and achieved through highlighting the main problems, successful analysis for existing situation, and the examining the proposed strategic plan. First, stating problem during the last few decades, Egyptian cities underwent through several significant transformations regarding their sizes, population densities, mobility and land use distribution. Due to the lack of a spatial decentralization policy, most of those cities experienced an exponential population growth and, therefore, are faced with serious problems. Those problems range from the lack of infrastructure, inadequate transportation networks connecting the cities with their hinterlands, illegal or even chaotic expansion, increasing densities, congestion at the center and including dramatic changes of land use. Highlighting the specific issues entailed with the Egypt’s second capital and second metropolitan national agglomeration: Alexandria city. The research adopted strategy takes into consideration the dynamics and requirements of urban growth and attempts to deal with the existing problems of the city towards two aspects: population growth/urban development aspect, and networking/transportation aspect. Accordingly, to the strategic development strategies prepared by General organization of physical planning for airport lake area, as it is considered to be an extension for the city center for Alexandria city it will be taken as a case study to test the proposed conceptual plan.

This chosen area is responding to the debates on the importance of polycentrism in contrast to the mono-centric development of cities; sociologists, economists, and geographers have developed several models, explaining where different types of people and businesses tend to exist within the urban settings. Various theories focusing on the distribution of densities within cities have also emerged: in 1945, Harris and Ullman (1945) introduced a polycentric model,
described as a more effective generalization of urban land uses, where large cities do not grow around one CBD, but are formed by the progressive integration of a number of separate nuclei in the urban pattern. While Space syntax describes the logic of society through its manifestation in spatial systems: how spaces are put together or the configuration of space relates directly with how people perceive, move through and use spatial systems of all kind, ranging from small domestic spaces to large-scale urban settlements (Karimi, 2012). The core concepts of space syntax can be explained through two fundamental propositions. The first proposition is that space is intrinsic to human activity, not a background to it. Space is shaped in ways that reflects the direct interaction between space and people, and through this the space is created, and the built environment, become humanized. The second core proposition of space syntax is that space is fundamentally a configurational entity (Hillier and Hanson, 1984; Hillier and Penn, 1991; Hillier, 1996; Hillier, 2008). Configuration, simply defined as simultaneously existing relations, is about the composition of the built form from the parts that are in a unique relationship with each other. Marcus (2007) defines the space syntax theory in a very understandable way, that the main variable of urban form that is analyzed within space syntax is accessibility and how the accessibility between spaces varies according to the changes in the configuration of urban form. Karimi (1997) adds that space syntax theory focuses on creating a platform for society and space, to give a spatial nature to society as well as a social dimension to space. The main important issue in enhancing polycentrism is through defining centers, sub-centers (centrality) and accessibility within the city.

The research will start by introducing a brief background on Alexandria city growth and development challenges, importance of study area, and moves to the implementation of the model. Finally, implementation of model should end with recommendations to the proposed conceptual plan for the area.

2. HISTORICAL BACKGROUND

Alexandria city occupies an area of about 300 km² and has a ten-fold increase in population of 4 million, with a density exceeding 1,200 per km² (Shouk, 2000). Population is expected to reach 5.4 million by 2015 (United Nations, 2008). This enormous urban growth requires precise detection with good management, prediction and planning. The city development and growth direction for Alexandria City Since 19th and 20th, the following were observed: The discrepancy between the population growth and spatial accessibility has increased recently. According to that, GOPP vision had a new vision for development for Airport lake, as it is considered to be one of Alexandria’s waterfront areas. Its location adjacency to Alexandria city centre, which may be developed as another center. In addition to that, it is characterized with multiple attracting elements that play main and important role in the urban and economic development in the strategic development scheme on the level of city such as; El Nozha Airport, (Airport Lake) it is part of lake Mariout and represent an area of 1375 feddan , Aviation club and Rowing club, existing range of urban agglomerations. In addition to that, that the study area is located at a site mediating the city entrances whether from the desert road and agricultural road. It is connected with the city by a group of regional and main roads that makes area easily connected to the whole city, as well as surrounding areas.

To summarize the importance of area on the level of connectivity and accessibility, as follows:

Strategic location in Alexandria’s main entrance, located near desert road, northern edge is surrounded by Agricultural road, from southern edge by the international coastal road, as shown in (figure 1), that illustrates the important road network connecting the site with surroundings and existing important features.

In the light of the above-mentioned challenges facing the future development and growth of Alexandria city, an adopted methodology will be used to examine the proposed plan for the Lake Airport lake as a new center in Alexandria, this methodology is based on integration of space syntax into GIS, this would stimulate a research oriented toward the analysis of urban system at different levels of abstraction. Starting by analysing the existing centers in Alexandria, using GIS quantitatively using cluster method, moving to spatial configuration of city using space...
syntax theories. thus, GIS provides on one hand a rich set of spatial data integration, analysis and visualization capabilities that support urban studies. On the other hand, the principles that underlie space syntax theory can extend the modelling capabilities of GIS, particularly in terms of the dissemination of recent advance and experimentation throughout the analysis of urban system. The space syntax could be considered both as alternative model of space at the cognitive level, and as a practical computational method for the analysis of urban structures and patterns (Claramant C., Klarquist B., Jiang B., 2002). the starting point will be based on analyzing the current spatial pattern and the centers and sub centers. Alexandria is divided into seven administrative districts, the study will focus on five districts in Alexandria: Al Montaza, East (sharq), Central (wassat), Gommrok, West (Gharb) districts, other districts like Al Amria and Borg Arab are not included in the analysis due to difficulty to get their data as mentioned before, but it should be implemented in the model as future study. Then analyzing the conceptual plan for a developing area like Airport lake as it could be considered as another center adjacent to the main city center.

3. DATASETS AND METHODS

The research main aim is to fill in the gab and provide a framework to inform the limited physical interventions by relating different layers of analysis and design, to enhance urban design process of the city. Thus, to examine the proposed master plan for Airport lake as a new nucleus for Alexandria, it is important to first analyze the existing successful centers and sub centers to be able to have criteria for the (centrality) and accessibility. There are different approaches to analyze centers and sub-centers, the adopted methodology, designed to use GIS Based approach using cluster method to provide quantitative figures for the identified problem, and integrating it with Space Syntax approach. Enabling an evident base method to be more precious in the solutions given and to help decision makers in urban design and planning process. Therefore, the analysis will be carried out through Four main steps illustrated in figure (2), the results of each step will be used in the following step to accomplish a composite model mentioned as follows;
1. City level: Step One: Defining the Sub-centers
   Using Geographic information system (GIS) for identification of existing centers and sub centers.

2. City level: Step Two: Existing centers formation
   Using Space Syntax methodology to investigate the spatial characteristic of city, and spatial and socio-economic characteristics of centers and sub centers.

3. Local level: Step Three: Enhancing polycentric development
   Overlaying the results from both stages to enrich the analysis and get recommendations for the planning process and decision making.

4. Local level: Step Four: Testing proposed conceptual design
   Examining the proposed conceptual plan for airport lake per the findings of the previous analysis of three steps.

3.1 STEP ONE:
USING (GIS) FOR CENTERS AND SUB-CENTERS IDENTIFICATION.

This section presents an empirical analysis of employment and population patterns of sub-centers in Alexandria; using GIS: 1- to identify employment sub centers using suitable method; 2- to apply it to data available in the region; 3- to analyze the functions and distributions of centers and their associated commuting flows. Thus, the Clustering method is used, it is one the most popular methodology for identifying employment center is based on employment density and
size, an approach developed by Giuliano and her colleagues (Giuliano and Small 1991; Giuliano et al. 2005). In the implementation of the model all data were provided from CAPMAS 2006 and an Origin Destination Matrix for peak hours for Alexandria 2010 produced by the Department of Transportation Civil Engineering, Alexandria University. The clustering method indicated 16 sub-center as shown in (Figure 3), it was observed that the number and size of employment centers are not only sensitive to the thresholds (D and E) but also to the transportation modes, major arterials and commercial activities. In addition to that, employment and activity sub-centers embody not only current opportunities for jobs and recreation, but also represents a criterion for formation of new centers as a future opportunity for development.

3.2 STEP TWO:
USING SPACE SYNTAX TECHNIQUES IN ANALYSING SPATIAL NETWORK OF CITY

This part contributes to the knowledge of urban spatial structure and dynamics, by the study of the functional movement of urban fabric of Alexandria city, Egypt through using the Space syntax, as it is capable of analysing the spatial network of the city how it can be described, how it effects on pattern of movement, land use and density can be measured. Thus, by understanding spatial networks, this could rebalance the planning of cities to achieve a better

Figure 3 - Identified employment Centers and sub centers using clustering method in Alexandria city, D= 20 job/ Feddan and E=15000 which will be used in step two of analysis.
harmony between global and local accessibility. Angular segment analysis is performed through node count analysis and integration analysis illustrated in figure (4), as they are considered to be best indicator of vehicular movement at different radii. Starting from global at radius 10,000 m, intermediate scale at 5000 and local scale at radii 2000 and 800. Global integration identifies the main street network of the city and the main centers, while local integration defines sub-center. The results achieved from step two at local scale radius 800 m will be overlaid with the results achieved from step one where Density D = 20 job/Feddan and Employment = 15,000 which will be used in part three of analysis. To compare between the sub-center and the network analysis and spatial configuration of sub centers, then moving to step three to analyse in depth some of selected centers and sub-centers. This measure helps to determine existing and potential local centers as these small radii also to identify the central destination zones for the neighbourhoods that attract potential pedestrian to-movement. This multi-centered structure reflects the actual characteristics of Alexandria, the figures show a remarkably true-to-life functional picture of the metropolitan city.

Figure 4 - Integration analysis and node count analysis at different radii for Alexandria city
4. RESULTS

To compare between the centers and sub-center identified and the network analysis, the result from step one will be overlaid with segment integration analysis at local level of radius 800m. As the spatial analysis, can give a true-to-life functional picture due to the powerful influence that natural movement has on the evolution of the urban pattern. This was proved in figure (5), where it is obvious that the street network analysis corresponded to the location of sub centers identified. Then Following this stage, two areas will be selected, one of them is the Central business district (CBD) and other area is a sub centers. These two areas are adjacent to the airport lake area that will be examined later. Also, the integration analysis of these two areas highlights high values, and corresponds with centers and sub-center identified from step two. The results of these areas will be analysed to get a correlation between accessibility and other factors like employment density and population density.

4.1 STEP THREE: OVERLAYING THE RESULTS OF GIS AND SPACE SYNTAX APPROACHES USING GEOGRAPHICALLY REGRESSION WEIGHTED APPROACH

![Segment integration analysis at radius 800 meters for the three areas of analysis](image)

Figure 5 - Segment integration analyses overlaid with sub centers identified of three areas
From an experiential point of view, it can be argued that what matters is the degree of accessibility to density, which is achieved by the design of urban fabric of streets and buildings. This relation will be analysed using Geographically Weighted Regression (GWR), as the regression analyses attempt to demonstrate the degree to which one or more variables potentially promote positive or negative change in another variable. In addition to that, spatially auto correlated (features near each other are more similar than those further away) and features behave differently based on their location/regional variation. This will be applied to the two areas to be able to extract the coefficient correlation (R²) between the degree of integration and employment density; the following results were found, the first area R² = 0.68, where the dark colour shows the areas where this relationship is significant and high. The high correlation value corresponds with the identified sub-centers and high integration value as shown in the scatterplot graph and figure (6).

Therefore, by comparing the results from selected areas shown in table (1), studied a correlation between accessible nodes showed strong relation with average employment density by 76% (R²=0.76) and 68% (R²=0.68). According to observed results, it is crucial to have a strong correlation between accessibility and employment density to have a successful sub center.

![Figure 6 - Scatterplot graph showing relation between integration and employment density, where R²= 0.68, 0.76 in two areas. Dark colours show high significant relation between employment center and integration.](image-url)

<table>
<thead>
<tr>
<th>Selected Areas</th>
<th>R² Correlation Between node count &amp; integration</th>
<th>Average Employment Density Job/Feddan</th>
<th>Average Employment Density Person/Feddan</th>
<th>Average Integration r=800</th>
<th>R² Correlation Between integration &amp; employment density</th>
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</thead>
<tbody>
<tr>
<td>Area 1</td>
<td>0.76</td>
<td>120</td>
<td>450</td>
<td>375</td>
<td>0.68</td>
</tr>
<tr>
<td>Area 2</td>
<td>0.78</td>
<td>100</td>
<td>400</td>
<td>349</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Table 1 - Comparison between selected areas
4.2 STEP FOUR: EXAMINING THE PROPOSED CONCEPTUAL PLAN FOR AIRPORT LAKE AREA.

It is obvious from the analysis carried for Alexandria city that Airport lake area is close to the main city center (Area 1) and sub centers (Area 2) in Alexandria, thus it is important to study how the proposed network (figure 7 (a)) and proposed land use (figure 7 (b)) will influence the whole city. This will be achieved by analyzing the spatial configuration at global and local scales at radius of 10,000, 5000, 2000 and 800 m, where spatial configuration at radius 800m will be studied with two near centers illustrated in figure (8), also a segment integration analysis is analyzed to the proposed area with adjacent centers, illustrated in figure (9) and a scatter-plot between the integration and node count is performed in figure (10).

Figure 7 - a) Proposed road network for Airport Lake area and b) proposed Land use

Figure 8 - integration analysis overlaid with proposed land use for airport lake area at radius of 800 m
The Analysis at global scale and intermediate scale shows that the proposed road network is connected with major road thus, linking the proposed area with the surroundings especially the city center and smouha sub center, but at a local scale the integration value is low. Therefore, the proposed road network succeeded in connecting the area with surroundings but still needs to be improved on the local scale, also it is important to consider the criteria for a successful urban center extracted from step one where D=20 job/Feddan and E=15000, Also correlation between accessible routes that correlated with average accessible population density by 72% (R²=0.726).

5. DISCUSSION AND REFLECTION ON BENEFITS OF APPLICATION

The adopted model was designed to test a proposed plan for the Lake Airport lake as a new center in Alexandria, thus it was important to identify existing centers and sub-centers, then analysing the spatial configuration of the city. This was fulfilled through four steps as follows:

1. Using GIS-based approach for identification of the centers and sub-centers using the clustering method. Three scenarios were tested with the clustering method, and the results were compared to the results of the layer based socio-economic analyses. The scenario with “D=20 jobs/feddan & total employment (E)=15000” was selected, as it was the one that achieves the nearest match between the outputs from the existing situation.

2. Using Space Syntax approach for analysing spatial configuration of city depending on Angular Segment Integration (ASI) analysis. ASI were analysed from global to local levels at different radii starting from 10 000 meters (for global) till 800 meters (for local). At each radius, different numbers of centers are identified per the scale of analysis. The resulted integration maps at radius 800 meters was selected, as it has produced results that corresponds with the identified centers and sub-centers from step one.
3. Integrating GIS and Space Syntax approaches, through the overlay of the resulted maps from the integration analysis and identified centers and sub-centers together. It was found that the areas that were identified as sub-centers completely match with the Angular Segment Integration analysis. Nevertheless, there were also other areas that have high integration values but do not match with the results from the clustering method. This is mainly due to the lack of complete GIS data in those areas. In addition, Geographically Weighted Regression analysis (GWR) was used to measure the correlation between the accessibility and employment density. The results where illustrated in the scatter plots in figures (6). The resulted R² is generally high and indicates high correlations between the two variables.

Through integrating space syntax and GIS-based approaches, this research emphasized how movement patterns and flows in cities are powerfully shaped by the street network; this relation shapes the evolution of the centers and sub-centers that affects the well-being of people in the city. The space syntax approach was used to analyse the road network accessibility quantitatively. The use of GIS allowed for the integration of additional data layers (such as socio-economic data) to improve the quality of analyses and findings. Space syntax proved to be a powerful tool that can deal with micro to macro scales, and therefore could be used in early stages to assist decision makers in evaluating different design and planning solutions. For a successful planning designs the proposed plans should be tested and examined for better scenarios and enhancing quality of life in city.

6. CONCLUSIONS

Enhancing polycentric development can be achieved through vitalizing existing center, sub-center by improving their density patterns, as well as connecting the existing centers with the newly proposed ones by means of accessible routes. The vitalization of centers and sub-centers requires that each center to be self-dependent, while enhancing the means of cooperation with other centers through adequate and accessible routes. GIS-based approaches, such as the clustering method, are powerful tools for the delineation and identification of existing centers and sub-centers within the urban environment. Setting appropriate criteria for the selection of the adequate analytical tools is vital to achieve efficiency in the outputs and analyses.

In this research, the spatial and socio-economic relationship was acknowledged through using configuration analytical methods in urban planning and design process. The social and physical theories of city and finally the spatial configuration related theories were introduced, and the following was concluded; There are several types of analytical tools, as previously mentioned. To fulfill the research needs, several criteria have been set (e.g. presence of spatial dimensions, could link space with people and users, dealing with different scales, and investigating system as a whole). Those criteria conform to the space syntax approach that will be used in the analysis of spatial pattern of city.

By examining the introduced theories, it was found that testing centrality and measuring accessibility could be a good determinant for enhancing polycentric development. Using Space Syntax approach requires studying the theory foundation, methodologies, parameters and new developments. It is concluded that; Angular Segment Analysis produces better correlation with observed vehicular flow than axial analysis. Thus, it will be used in the analysis of network configuration of city. Thus, using Space Syntax approach through Depthmap software and Geographic Information system (GIS) would give the best results. Using both approaches could integrate different layers to analysis and create a composite model.

The adoption of the proposed methodology and model on the selected application has led to the following conclusions; The research sets a new approach to understand the physical pattern of city, based on the cause and effect of spatial- socio-economic relationships. This approach is applied through using the clustering method and Space Syntax tool and then integrating both tools together. The research introduced quantitative data about the existing centers and sub-centers with the employment density ratio, thus this would help to create liveable successful sub-center.
The research highlighted the significant correlation between accessible routes that correlated with average accessible population density by 72% ($R^2=0.726$) in the livable sub-center and it identified the actual routes in real life. This could be used further in create livable successful sub-centers. The investigation model could assist decision maker in developing their action planes for interventions within the city.
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General Organization of Physical planning, (GOPP) publication, 2012, Plans And Achievements, first edition, Ministry of Housing, utilities and urban development
ABSTRACT
This study focuses on seven parks in Chicago, including Grant Park, Lincoln Park, Humboldt Park, Garfield Park, Douglas Park, Jackson Park, and Washington Park, to examine their accessibility within the city. Their accessibility is divided into three questions, through the analysis of integration, choice and connectivity values to see if their spatial configuration in the city has an affect on the people living in community areas around them.

In order to measure accessibility and study the socio-spatial relationships of the parks, analysis via the means of Space Syntax has been conducted. Additionally, Depthmap analysis of the parks is compared with information obtained from the city census, which reveal that all seven parks lie in neighbourhoods that vary not just geographically, but also racially and economically.

The analysis concludes that it is not always the most integrated or connected parks that lie in the city centre. Additionally, spatial configuration in terms of integration and connectivity does not necessarily contribute to social conditions such as housing or poverty levels, but sometimes is a result of historical factors such as Chicago’s housing segregation.

KEYWORDS
Chicago; Parks; Accessibility; Space Syntax; Demographic

1. INTRODUCTION
Parks, especially for city-dwellers, have long been a place for recluse and recreation. Their value in the world of architecture, planning, and use has been questioned, and has been re-evaluated over time. What parks play as their role in the future of cities remains to be seen, but the simple fact that they are open spaces for the public to use allows for debate on how they are or are not being used, and the most affective ways they can play a role in the sustainability of cities.

The main goal of this study is to explore seven prominent parks within the city of Chicago, and to see what spatial and social characteristics they embody within the city as a whole, but also within the neighbourhoods they lie in. Chicago has a long history of parks, starting from the inception of the city itself, and offers not just an array of services that the parklands provide, but also invests and promotes in community activities year round. Questions about the roles of parks in modern day planning in the United States have evolved to not just parks being a place of recluse, but also how they can play a productive role in social and environmental planning in order to make cities more sustainable (Cranz, 1989). A great emphasis has been placed on the design of parks and how they are used in the communities and neighbourhoods they lie in. As Byrne and Wolch write, parks are “paradoxically described as crime havens, treasured family refuges, and oasis for urban residents” but there is no concrete solution to having a successful implementation of a so-called utopian park, since they vary in “size, age, design, ornamental embellishments, planting, facilities, maintenance, and patterns of use”
While there have been studies conducted in the past based on parks and their relationships with ethnographic demographics as well as other studies looking at accessibility or spatial characteristics, the combination of studying both, the spatial as well as social analysis of parks are sparse. The interest in studying parks in Chicago is based on the fact that it not only occupies a large physical space in urban life, but also the fact that the parks that are being studied in this research are the first parks that were created during the inception of the city itself. While prominent researchers like Galen Cranz and Paul Gobster have explored in great detail the history, designs, perils and successes of Chicago parks, little has been explored in terms of spatial configuration of the parks within the city.

One of the aims of this research is to study Chicago parks in a new light, specifically the accessibility of parks, using tools such as Space Syntax theory and methods to reveal, perhaps a different narrative on the role that parks have within the urban context. This study aims to answer the following questions in regards to parks and accessibility: do the parks allow for people to connect across different neighbourhoods from the city?; does the spatial configuration of the parks allow for the possibility of social interaction due to their virtue of proximity?; and lastly, do the parks’ spatial location as well as characteristics reveal anything about the neighbourhoods that they lie in?

2. DATASETS AND METHODS

2.1 SYNTACTIC ANALYSIS

The importance of syntactic analysis is to not only produce images that show where parks are integrated and connected, but also provide data for each park, therefore offering insight into unique characteristics that each park has. As Hillier writes, “space syntax explains how cities work – how space, movement, land uses, human activity and psychology combine to create the complex forms we occupy and experience,” hence it being a useful tool when studying urban spaces such as parks (2016, p. 199).

Before studying the parks themselves, a segment analysis has been done within Chicago city limits, so as to provide an initial, brief insight into any patterns that one can find while looking at the city. A segment map (Figure 1), which is used in the software called Depthmap, is essentially a linear representation of urban spaces composed of axial lines, which are defined by the longest straight lines that represent a point in space (Hillier and Hanson, 1984). The axial map “basically captures the cognitive accessibility in movement space in terms of directionality. With the axial map it is possible to quantitatively measure distance in number of changes in direction, in terms of ‘axial steps’” (Ståhle, 2009, 7). With the help of the segment map, syntactic analysis can examine integration and choice values. As Hillier writes, integration shows “mathematical closeness, which measures how close each segment is to all others” (2009, p.4). Furthermore, integration values reveal how connected streets and areas are to each other (Hillier and Hanson, 1984). Choice on the other hand, is indicative of the word itself, whereby values indicate the possibility of segments that can be chosen between any two points in order to reach a destination.

The importance of choice values is that it measures “mathematical betweenness, which calculates how many distance-minimising paths between every pair of segment lies on under different definitions of distance” (Hillier, 2009, p.4). Choice values are often used to forecast pedestrian and vehicular movement. Thus, the higher the choice values are, the shorter the paths are to get from the point of origin to the destination. One of the important steps in order to measure accessibility is to compare the syntactic values of each park, be it choice, integration, or connectivity.

In order to continue the analysis in a manner that would help visualise the parks and their connection to the city, the segment map was imported into qGIS, one of the variations of Geographic Information Systems. GIS is often used for planning and management purposes,
allows for segment analysis, and is especially useful when studying aspects such as accessibility. Using the inbuilt feature of the Bing road map, polygons, or ‘shapes’ of the parks were drawn out, a necessary step in order to measure accessibility. Furthermore, having the polygons of the parks allows for analysis between the parks and the segments, including integration, choice, and connectivity values.

Accessibility of parks can be measured in various ways, but for the purposes of this study, it was important to create buffers of the polygons. Creating a buffer involves implementing different radii of the parks with respect to the segments. Buffer distances (using ‘as the crow flies’ technique) of 60 meters, 400 meters, 1200 meters and 2000 meters have been done, as it measures the geographic centre of each park with respect to its surroundings (Nicholls, 2001).

The importance of setting up buffers at different distances helps capture accessibility both at a local and global scale.

Besides the buffers themselves, it is important to note that the mean values of integration, choice, and connectivity are measured in several radii including 400, 800, 1200, 2000, 5000, 10000, 20000, and n to properly compare and contrast the parks with each other, as well as to see if there are any differences within the various buffer radii. Essentially, this study involves both the analysis of the integration, choice, and connectivity of the segments as a whole, but also their interaction with the parks, thereby revealing some answers of accessibility as well as spatial configuration.

Other spatial characteristics around the parks can be revealed through the means of foreground and background networks. The foreground network can reveal “linked centres at all scales, from a couple of shops and a café at the smallest scale to whole sub-cities at the largest, all set into a background network of mainly residential space” (Hillier, 2009, 4). The benefits of analysing the foreground network is that it provides additional knowledge as to how the parks are situated within the communities they lie in.

![Figure 1 - Selected Parks in Segment Map](image-url)
In order to examine the first research question, which asks, does the spatial configuration of the parks allow for the possibility of social interaction due to their virtue of proximity? In order to study this question, integration values are necessary to look at, particularly mean NAIN values, as they reveal ease of accessibility in the street network. In other words, integration measures “to-movement potential of a segment as a destination, since the measure describes its accessibility or how easy it is to get to from all other segments” (Hillier, 2009, p. 131). The second part of the research question asks, do the parks allow for people to connect across different neighbourhoods from the city? Choice values, or mean NACH values in syntactic terms, are used to measure and analyse the second question. Mean NACH values “define a network,” specifically the background network of neighbourhoods (Hillier, 2005, p.26). Unlike normalised integration values that represent to-movement, NACH values signify through movements. The more segregated the depth of each segment is, the more likely it is that choice values will also reduce. Lastly, the research questions, do the parks’ spatial locations as well as characteristics reveal anything about the neighbourhoods that they lie in? An analysis of angular connectivity has been conducted to best understand the components of the last question. Connectivity is “a property that can be seen from each space, in that wherever one is in the space one can see how many neighbouring spaces it connects to.” (Hillier, 2007, p. 94). Therefore, the measures of connectivity indicate the number of immediate neighbourhoods that are directly connected to the respective parks. By measuring connectivity, the data can provide an insight into how intelligible and permeable the parks are for residents and users alike.

2.2 ETHNOGRAPHIC AND STATISTICAL DATA

The combination of syntactic analysis with that of ethnographic and statistical data provided by the city census can prove to be useful due to the fact that Chicago has a rich history of social and housing segregation. Racial divides have led to certain areas within the city in deep poverty, and studies reveal that areas with higher poverty rates and regions with ethnic minorities “were significantly associated with reduced availability of green spaces, parks, and public sports areas, while areas with higher household income had a greater frequency of such amenities” (Higgs et al., 2012, p. 328). Therefore, the amalgamation of data from both the syntactic analysis as well as demographic data from the city census and statistics encompass the spatial as well as the social realm.

3. CASE STUDIES

The history of parks in Chicago goes back to the 19th century with the Chicago Park District being one of the oldest and largest park districts in the United States (Bachrach, 2001). The story of the preservation, creation, and continuation of parklands began around the 1850s, with the emergence of a new government in Chicago, whose citizens rallied for a comprehensive park system so people could enjoy the views of Lake Michigan, as well as have public spaces available without the interference of private companies and landowners. This led to the beginnings of the first and largest park in Chicago, known as Lincoln Park. Consequently, the creation of Lincoln Park led to three independent park commissions known as the Lincoln, South, and West Park Commissions in 1869, with the goal of forming a “unified ribbon of green” that would encircle Chicago (Bachrach, 2001). Furthermore, with much lobbying from the public, the government of Chicago decided to keep the land east of Michigan Avenue, formerly known as Lake Park, now dubbed Grant Park, to be a public space permanently. By 1890, Chicago had a large and expansive park system, with Lincoln Park to the North, Garfield, Douglas, and Humboldt Parks to the West, Grant Park to the East, and Washington Park and Jackson Park to the South, therefore ensuring that the lakeshore front remained away from the private sectors and accessed and used purely for and by the public (McCarthy, 1972). By the end of the Great Depression, it was agreed upon that the different Park Commissions consolidate as one entity, now known as the Chicago Park District.
Indeed, it can be said that the above-mentioned parks were the first and most prominent parks that laid the foundation to the addition of subsequent parks within the city as well as Chicago-land in the future. What sets them apart from the rest of the parks is their shared history, dating back to the beginning of the formation of the city itself, to the fact that each of the parks are located in different areas of the city, thereby having their own distinct history with the neighbourhoods that they lie in.

In terms of syntactic analysis, Table 1 lists out the average for integration and choice values, as well as segment length.

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</tr>
</tbody>
</table>

Table 1

As can be seen from the table above, when looking at choice values, as the radius decreases, choice values increase, thereby allowing for more through movement. The opposite phenomenon happens when looking at integration, or NAIN values, where as the radii increase, so do the values. Supported by Table 1, Figure 2 illustrates that choice values are especially high in the city centre, which is indicated by the high concentration of red segment clusters. What is interesting to note is that there are clusters in close proximity to all the parks, thereby indicating that there are high levels of choice values around the parks.

Figure 2: NAIN R₄₀₀ vs NACH R₄₀₀
4. ANALYSIS

4.1 MEAN NAIN VALUES

The importance of syntactic data, including integration and choice values is that they reveal to and through movements in a city. The first set of data helps to answer the first research question, which asks if the parks allow for people to connect across different neighbourhoods from the city. The tables and figures below present the mean NAIN values conducted at four different buffers, 60m, 400m, 1200m, and 2000m. The reason that these particular radii have been chosen is due to the fact that it depicts both local and global movements. As mentioned previously, the importance of obtaining integration values is that it highlights to movements on the foreground scale, from centre to centre (Hillier, 2001, 2009). Essentially, mean NAIN values are not just analysed at different radii for just a segment analysis, but also different buffer radii that depict what the relationship of the segments have with the parks themselves.

As can be seen from Table 2, the data shows mean integration values of the segments at the 60m buffer radius of the parks. When looking at NAIN values at the 2000 radius, there is an unusual spike. Values dip and surge at an oscillating fashion, where integration decreases significantly at 1200r and then increase again at 800r and finally decreases again at 400r.

<table>
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<tr>
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<th>MEANNorm2000</th>
<th>MEANNorm1000</th>
<th>MEANNorm500</th>
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<td>1.593</td>
<td>1.431</td>
<td>2.509</td>
<td>1.649</td>
<td>2.084</td>
<td>1.999</td>
</tr>
<tr>
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<td>1.472</td>
<td>1.463</td>
<td>1.376</td>
<td>2.341</td>
<td>1.534</td>
<td>1.547</td>
<td>1.549</td>
</tr>
<tr>
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<td>1.441</td>
<td>1.382</td>
<td>1.324</td>
<td>2.231</td>
<td>1.457</td>
<td>1.851</td>
<td>1.746</td>
</tr>
<tr>
<td>Jackson Park</td>
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<td>1.239</td>
<td>1.297</td>
<td>1.743</td>
<td>1.275</td>
<td>1.619</td>
<td>1.527</td>
</tr>
<tr>
<td>Washington Park</td>
<td>1.490</td>
<td>1.431</td>
<td>1.399</td>
<td>2.968</td>
<td>1.515</td>
<td>1.788</td>
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</table>

Table 2 - Mean NAIN at 60m Buffer

<table>
<thead>
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<th>MEANNorm2000</th>
<th>MEANNorm1000</th>
<th>MEANNorm500</th>
<th>MEANNorm2006</th>
<th>MEANNorm1100</th>
<th>MEANNorm5000</th>
<th>MEANNorm2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln Park</td>
<td>2.185</td>
<td>2.002</td>
<td>1.764</td>
<td>1.512</td>
<td>1.450</td>
<td>1.451</td>
<td>1.515</td>
</tr>
<tr>
<td>Grant Park</td>
<td>2.337</td>
<td>2.092</td>
<td>1.846</td>
<td>1.960</td>
<td>1.555</td>
<td>1.502</td>
<td>1.510</td>
</tr>
<tr>
<td>Humboldt Park</td>
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<td>2.363</td>
<td>1.984</td>
<td>1.641</td>
<td>1.654</td>
<td>1.867</td>
<td>1.722</td>
</tr>
<tr>
<td>Garfield Park</td>
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<td>2.746</td>
<td>1.985</td>
<td>1.631</td>
<td>1.482</td>
<td>1.418</td>
<td>1.481</td>
</tr>
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<td>Douglas Park</td>
<td>2.268</td>
<td>2.152</td>
<td>1.886</td>
<td>1.650</td>
<td>1.503</td>
<td>1.473</td>
<td>1.506</td>
</tr>
<tr>
<td>Jackson Park</td>
<td>1.759</td>
<td>1.718</td>
<td>1.831</td>
<td>1.309</td>
<td>1.282</td>
<td>1.331</td>
<td>1.449</td>
</tr>
<tr>
<td>Washington Park</td>
<td>2.037</td>
<td>1.931</td>
<td>1.841</td>
<td>1.559</td>
<td>1.481</td>
<td>1.459</td>
<td>1.510</td>
</tr>
</tbody>
</table>

Table 3 - Mean NAIN at 400m Buffer

<table>
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<th>Park</th>
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<th>MEANNorm1000</th>
<th>MEANNorm500</th>
<th>MEANNorm2006</th>
<th>MEANNorm1100</th>
<th>MEANNorm5000</th>
<th>MEANNorm2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln Park</td>
<td>1.255</td>
<td>2.095</td>
<td>1.624</td>
<td>1.624</td>
<td>1.537</td>
<td>1.495</td>
<td>1.518</td>
</tr>
<tr>
<td>Grant Park</td>
<td>2.301</td>
<td>2.092</td>
<td>1.639</td>
<td>1.717</td>
<td>1.508</td>
<td>1.509</td>
<td>1.367</td>
</tr>
<tr>
<td>Humboldt Park</td>
<td>2.509</td>
<td>2.387</td>
<td>2.029</td>
<td>1.737</td>
<td>1.636</td>
<td>1.583</td>
<td>1.558</td>
</tr>
<tr>
<td>Garfield Park</td>
<td>2.410</td>
<td>2.287</td>
<td>2.026</td>
<td>1.731</td>
<td>1.613</td>
<td>1.558</td>
<td>1.545</td>
</tr>
<tr>
<td>Douglas Park</td>
<td>2.442</td>
<td>2.240</td>
<td>1.951</td>
<td>1.483</td>
<td>1.578</td>
<td>1.634</td>
<td>1.552</td>
</tr>
<tr>
<td>Jackson Park</td>
<td>1.846</td>
<td>1.820</td>
<td>1.648</td>
<td>1.461</td>
<td>1.412</td>
<td>1.424</td>
<td>1.561</td>
</tr>
<tr>
<td>Washington Park</td>
<td>2.086</td>
<td>2.018</td>
<td>1.804</td>
<td>1.631</td>
<td>1.574</td>
<td>1.546</td>
<td>1.558</td>
</tr>
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</table>

Table 4 - Mean NAIN at 1200m Buffer

<table>
<thead>
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<th>MEANNorm1000</th>
<th>MEANNorm500</th>
<th>MEANNorm2006</th>
<th>MEANNorm1100</th>
<th>MEANNorm5000</th>
<th>MEANNorm2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln Park</td>
<td>1.274</td>
<td>2.120</td>
<td>1.694</td>
<td>1.577</td>
<td>1.560</td>
<td>1.532</td>
<td>1.516</td>
</tr>
<tr>
<td>Grant Park</td>
<td>2.346</td>
<td>2.186</td>
<td>1.854</td>
<td>1.712</td>
<td>1.624</td>
<td>1.567</td>
<td>1.552</td>
</tr>
<tr>
<td>Humboldt Park</td>
<td>2.511</td>
<td>2.396</td>
<td>2.045</td>
<td>1.754</td>
<td>1.649</td>
<td>1.589</td>
<td>1.572</td>
</tr>
<tr>
<td>Garfield Park</td>
<td>2.741</td>
<td>2.269</td>
<td>2.036</td>
<td>1.731</td>
<td>1.621</td>
<td>1.565</td>
<td>1.556</td>
</tr>
<tr>
<td>Douglas Park</td>
<td>2.451</td>
<td>2.259</td>
<td>1.981</td>
<td>1.731</td>
<td>1.629</td>
<td>1.568</td>
<td>1.555</td>
</tr>
<tr>
<td>Jackson Park</td>
<td>1.512</td>
<td>1.907</td>
<td>1.755</td>
<td>1.564</td>
<td>1.455</td>
<td>1.493</td>
<td>1.549</td>
</tr>
<tr>
<td>Washington Park</td>
<td>2.058</td>
<td>1.997</td>
<td>1.781</td>
<td>1.577</td>
<td>1.501</td>
<td>1.486</td>
<td>1.526</td>
</tr>
</tbody>
</table>

Table 5 - Mean NAIN at 2000m Buffer

While all the seven parks behave similarly in terms of integration values at different radii, it is important to note that it is not Grant Park, which is located within the city centre, but rather Humboldt Park to the west that has higher NAIN values, especially at the 2000 and 800 radii. Integration values at the 400m buffer radius is different from that of the 60m buffer radius in that all the parks' values decrease as radii decrease. Furthermore, Jackson Park has the lowest values when compared to the rest of the parks, while Humboldt Park has the highest NAIN values at the highest radius.
Like the integration values of the 400 meter buffer radius, mean NAIN values at the 1200 meter buffer radius decrease as the radii decrease. Again, Jackson Park consistently has the lowest values when compared with the rest of the Parks, while Humboldt Park has the highest value at the radii 20000 and 10000.

### 4.2 MEAN NACH VALUES

Moving on from integration values, the second research question asks if the spatial configuration of the parks allows for the possibility of social interaction due to their virtue of proximity. This leads to the next level of analysis, which is the mean choice, or NACH values. Normalised choice values reveal the shortest distance required to go from one point to another. Unlike integration which measures movement from origin to destination, choice values select the “intervening spaces that must be passed through” to go from one place to another (Hillier and Iida, 2005, p. 479).

<table>
<thead>
<tr>
<th>Park</th>
<th>MEAN NACH 20000</th>
<th>MEAN NACH 11000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 3000</th>
<th>MEAN NACH 12000</th>
<th>MEAN NACH 8000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 000</th>
<th>MEAN NACH N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln Park</td>
<td>1.061</td>
<td>1.023</td>
<td>1.042</td>
<td>1.054</td>
<td>1.042</td>
<td>1.018</td>
<td>1.592</td>
<td>0.919</td>
<td></td>
</tr>
<tr>
<td>Grant Park</td>
<td>1.015</td>
<td>1.035</td>
<td>1.054</td>
<td>1.066</td>
<td>1.054</td>
<td>1.031</td>
<td>1.706</td>
<td>0.958</td>
<td></td>
</tr>
<tr>
<td>Humboldt Park</td>
<td>1.047</td>
<td>1.085</td>
<td>1.071</td>
<td>1.074</td>
<td>1.067</td>
<td>1.043</td>
<td>1.609</td>
<td>1.019</td>
<td></td>
</tr>
<tr>
<td>Garfield Park</td>
<td>1.044</td>
<td>1.065</td>
<td>1.084</td>
<td>1.086</td>
<td>1.063</td>
<td>1.017</td>
<td>1.598</td>
<td>1.001</td>
<td></td>
</tr>
<tr>
<td>Douglas Park</td>
<td>1.016</td>
<td>1.032</td>
<td>1.047</td>
<td>1.048</td>
<td>1.032</td>
<td>1.024</td>
<td>1.511</td>
<td>0.993</td>
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</tr>
<tr>
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<td>0.981</td>
<td>1.005</td>
<td>1.024</td>
<td>1.016</td>
<td>0.998</td>
<td>1.519</td>
<td>0.888</td>
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</tr>
<tr>
<td>Washington Park</td>
<td>1.041</td>
<td>1.062</td>
<td>1.077</td>
<td>1.081</td>
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<td>1.013</td>
<td>1.467</td>
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Table 6 - Mean NACH at 60m Buffer

<table>
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<th>MEAN NACH 11000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 3000</th>
<th>MEAN NACH 12000</th>
<th>MEAN NACH 8000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 000</th>
<th>MEAN NACH N</th>
</tr>
</thead>
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<td>1.065</td>
<td>1.055</td>
<td>1.032</td>
<td>1.613</td>
<td>0.957</td>
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</tr>
<tr>
<td>Grant Park</td>
<td>1.034</td>
<td>1.038</td>
<td>1.053</td>
<td>1.062</td>
<td>1.050</td>
<td>1.018</td>
<td>1.711</td>
<td>0.956</td>
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</tr>
<tr>
<td>Humboldt Park</td>
<td>1.054</td>
<td>1.071</td>
<td>1.079</td>
<td>1.083</td>
<td>1.072</td>
<td>1.046</td>
<td>1.608</td>
<td>1.024</td>
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</tr>
<tr>
<td>Garfield Park</td>
<td>1.014</td>
<td>1.055</td>
<td>1.072</td>
<td>1.071</td>
<td>1.058</td>
<td>1.031</td>
<td>1.571</td>
<td>0.993</td>
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</tr>
<tr>
<td>Douglas Park</td>
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<td>1.064</td>
<td>1.066</td>
<td>1.052</td>
<td>1.013</td>
<td>1.537</td>
<td>1.003</td>
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</tr>
<tr>
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<td>1.015</td>
<td>1.038</td>
<td>1.056</td>
<td>1.037</td>
<td>1.014</td>
<td>1.509</td>
<td>0.915</td>
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</tr>
<tr>
<td>Washington Park</td>
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<td>1.026</td>
<td>1.046</td>
<td>1.044</td>
<td>1.029</td>
<td>1.009</td>
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Table 7 - Mean NACH at 400m Buffer

<table>
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<th>MEAN NACH 11000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 3000</th>
<th>MEAN NACH 12000</th>
<th>MEAN NACH 8000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 000</th>
<th>MEAN NACH N</th>
</tr>
</thead>
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<tr>
<td>Lincoln Park</td>
<td>0.974</td>
<td>0.948</td>
<td>0.971</td>
<td>0.974</td>
<td>0.964</td>
<td>0.912</td>
<td>1.288</td>
<td>0.856</td>
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<td>1.016</td>
<td>1.046</td>
<td>1.064</td>
<td>1.017</td>
<td>0.960</td>
<td>0.915</td>
<td>1.474</td>
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<td>1.052</td>
<td>1.065</td>
<td>1.061</td>
<td>1.046</td>
<td>1.010</td>
<td>1.564</td>
<td>1.025</td>
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</tr>
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<td>Garfield Park</td>
<td>1.025</td>
<td>1.052</td>
<td>1.075</td>
<td>1.072</td>
<td>1.047</td>
<td>1.011</td>
<td>1.561</td>
<td>0.974</td>
<td></td>
</tr>
<tr>
<td>Douglas Park</td>
<td>0.974</td>
<td>0.993</td>
<td>1.031</td>
<td>1.043</td>
<td>1.031</td>
<td>0.979</td>
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</tr>
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<td>0.995</td>
<td>1.016</td>
<td>1.025</td>
<td>1.001</td>
<td>0.979</td>
<td>1.381</td>
<td>0.896</td>
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</tr>
<tr>
<td>Washington Park</td>
<td>1.036</td>
<td>1.089</td>
<td>1.101</td>
<td>1.106</td>
<td>1.083</td>
<td>1.049</td>
<td>1.407</td>
<td>0.981</td>
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</tr>
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Table 8 - Mean NACH at 12000m Buffer

<table>
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<th>MEAN NACH 20000</th>
<th>MEAN NACH 11000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 3000</th>
<th>MEAN NACH 12000</th>
<th>MEAN NACH 8000</th>
<th>MEAN NACH 4000</th>
<th>MEAN NACH 000</th>
<th>MEAN NACH N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lincoln Park</td>
<td>0.957</td>
<td>0.981</td>
<td>1.004</td>
<td>1.014</td>
<td>1.006</td>
<td>0.930</td>
<td>1.460</td>
<td>0.853</td>
<td></td>
</tr>
<tr>
<td>Grant Park</td>
<td>1.017</td>
<td>1.034</td>
<td>1.046</td>
<td>1.043</td>
<td>1.031</td>
<td>1.007</td>
<td>1.709</td>
<td>0.959</td>
<td></td>
</tr>
<tr>
<td>Humboldt Park</td>
<td>1.024</td>
<td>1.039</td>
<td>1.066</td>
<td>1.054</td>
<td>1.052</td>
<td>1.015</td>
<td>1.633</td>
<td>1.003</td>
<td></td>
</tr>
<tr>
<td>Garfield Park</td>
<td>1.064</td>
<td>1.031</td>
<td>1.054</td>
<td>1.048</td>
<td>1.030</td>
<td>1.006</td>
<td>1.607</td>
<td>0.957</td>
<td></td>
</tr>
<tr>
<td>Douglas Park</td>
<td>1.002</td>
<td>1.015</td>
<td>1.034</td>
<td>1.039</td>
<td>1.031</td>
<td>1.010</td>
<td>1.494</td>
<td>0.975</td>
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</tr>
<tr>
<td>Jackson Park</td>
<td>0.917</td>
<td>0.945</td>
<td>0.972</td>
<td>0.992</td>
<td>0.985</td>
<td>0.973</td>
<td>1.479</td>
<td>0.839</td>
<td></td>
</tr>
<tr>
<td>Washington Park</td>
<td>1.013</td>
<td>1.041</td>
<td>1.059</td>
<td>1.066</td>
<td>1.059</td>
<td>1.011</td>
<td>1.471</td>
<td>0.947</td>
<td></td>
</tr>
</tbody>
</table>

Table 9 - Mean NACH at 20000m Buffer

It is noteworthy that in buffers 400m, 1200m, and 2000m, Grant Park appears to have the highest choice values at the lowest radius. What makes the parks different from each other then, are individual values when compared to each other. Therefore, the choice for connecting across different neighbourhoods through the means of parks is highest only on the local level. In other words, it is most convenient to access parks that are closest to the point of origin and through movement.
4.3 ANGULAR CONNECTIVITY

The last question in regards to parks and accessibility asks if the parks’ spatial location as well as characteristics reveal anything about the neighbourhoods that they lie in. In order to examine this question, the mean angular connectivity is used to measure the number of spaces immediately connecting to the space of origin (Hillier and Hanson, 1984). By using connectivity for syntactic analysis, data can reveal how the parks are connected with respect to each other, as well as within the city.

For the purposes of a better visual illustration, the polygons of the parks reveal which parks are most connected at different buffers. At buffers 60m and 400m (Figure 3), it appears that Grant Park has the highest levels of connectivity while Lincoln Park has the lowest. What is interesting to note is that Humboldt Park has the second highest value in connectivity, despite the fact that it is not located within the city centre.

When comparing Figures 3 and 4, it is imperative to examine the difference in connectivity values, especially when comparing them to each other. While mean connectivity values remain the lowest at Lincoln Park and Jackson Park, it is important to note that at higher buffer radii, Jackson Park’s connectivity values are lower than Lincoln Park’s.

Furthermore, an unexpected shift occurs, where Humboldt Park’s connectivity increases, and is higher than Grant Park, which is centrally located. Apart from the higher connectivity values of Humboldt Park at both the 1200m and 2000m buffers, when looking at Garfield Park and Douglas Park, there are differences in values when the two are compared to each other. For example, at the 1200m buffer radius, the connectivity values of Garfield Park are higher than that of Douglas Park. However, at the 2000m buffer radius, Douglas Park’s connectivity values are higher than Garfield Park. However, at the 2000m buffer radius, Douglas Park’s connectivity values are higher than Garfield Park. Looking at Washington Park, its connectivity values are higher at buffer radius 1200,

with a mean value of 5.038, and decreases to 4.868 at the 2000m buffer radius. What is interesting to note is that as the buffers increase, the park that has the highest integration, which is Grant Park in the city centre, is not the park with the highest connectivity. Instead, the park that is the most connected is Humboldt Park, one of the three parks located on the west side of Chicago. On the opposite side, Jackson Park has the least angular connectivity, suggesting that it is the most isolated of the parks.
4.4 CENSUS DATA

While it is true that the seven parks chosen in this research were green spaces created during the inception of Chicago, the city itself has evolved by not just expanding structurally, but also demographically. The combination of the influx of migration as well as the long history of racial and housing segregation has resulted in large portions of the city divided by race, and therefore income. Consequently, “many northern and mid-western cities […] had separate parks for Whites and African-Americans, with people of colour confined to a park-deprived urban core while Whites enjoyed a park-abundant suburban periphery” (Kraus, 1969, cited in Byrne and Wolch, 2009, p. 747). For the purposes of this research, it is important to look at parks with respect to the socio-spatial relations within the city.

Figure 5 depicts the average income (USD) per community area. It is clear to see that those earning the highest income live closer to Grant Park and Lincoln Park. Similarly, looking at unemployment rates, community areas closer to Grant Park and Lincoln Park have lower unemployment rates while those areas in the south side and west side have higher unemployment rates. Lastly, figure 6 depicts community areas with percentages below the poverty line. Areas closer to Grant Park and Lincoln Park have lower percentages of poverty while those living closer to the west side parks and the south side parks have higher rates of poverty. Particularly, the community area by Douglas Park appears to have the highest poverty rate when compared to areas around the other six parks.
5. DISCUSSION

It is clear that when looking at integration and choice values, integration and to-movement are more on a global scale as values are higher at larger radii, while choice values are based more on a local scale, as values increase only when radii decrease. So when the first question asks if the parks allow for people to connect across different neighbourhoods from the city, the use of integration values suggest that to-movement does occur, and since integration values are higher at a larger radius, it is suggested that there are more possibilities to connect across different neighbourhoods. However, it is important to note that just because the possibilities to connect to other parks are there, that does not necessarily mean that such connections will be made. It is the combination of the virtue of proximity as well as what the parks have to offer in terms of services that can result in additional trips being made to parks that might be far from home. Second, the research questions if the spatial configuration of the parks allow for the possibility of social interaction due to their virtue of proximity. Choice values suggests that it is less likely for such activity to occur since NACH values reveal that there is a higher possibility...
of interaction only if people are within the same park or are in the vicinity of the area. The last question asks if the parks’ spatial location as well as characteristics reveal anything about the neighbourhoods that they lie in. The answer to the last question is not definitive due to the fact that spatial location does not necessarily reveal an important aspect about the social surroundings, including the neighbourhoods that they lie in. For example, Lincoln Park and Jackson Park are among the least integrated or connected parks and lie on opposite sides of the city, with Lincoln Park to the north and Jackson Park to the south. Yet, those who live around the Lincoln Park area earn a higher income than those that live in Jackson Park. Similarly, Humboldt Park, which is situated in the west side of Chicago, is highly integrated and connected like Grant Park which is located within the city centre. Yet, those that live by Humboldt Park have higher unemployment rates, have lower income, and have higher rates of those that live below poverty lines. With such examples like the ones stated above, it could be suggested that spatial properties of the parks do not necessarily reveal why there is a demographic segregation, and could instead be attributed to social causes that may have contributed to it. After all, when looking at the racial demographics, there is a clear divide in the fact that ethnic minorities live more on the west and south sides of Chicago. This, when combined with unemployment, poverty, and income suggests that those who are of colour, and especially those that identify as Latinos or African-Americans, are among those who live under conditions of higher rates of poverty, while those that earn higher wages happen to be White and live in or closer to the city centre. Despite the fact that African-Americans had been emancipated since the Civil War, "housing segregation in the United States developed slowly and deliberately," and has resulted in cities like Chicago to continue to remain heavily segregated in the present day (Seitles, 1998, p. 92). When they moved up north during the industrial revolution, Chicago’s South Side soon came to be known as ‘South Side Black Belt’ (Hirsch, 2009). This suggests that those that live closer to the city centre near Grant Park or by Lincoln Park have easier access to additional park amenities offered at the two parks than those that live farther away.

This research has used different methodological tools in space syntax with the aim to answer the socio-spatial relations of parks in Chicago. While it can be determined that the spatial configuration of the parks do not necessarily determine the social demographics around the parks, further investigation can be conducted as to how the parks are used. For example, Lincoln Park provides more services and is the largest and most visited park in the city. Studying the demographics of the parks by counting the number of people that visit on a daily basis, as well as calculating demographics could prove useful, especially for planning purposes. Despite the fact that Humboldt Park is more integrated and connected, it is Lincoln Park and Grant Park that are more widely used. By analysing demographics of park users, planners may be able to better understand how to use park space effectively within the communities they lie in.

6. CONCLUSIONS

Cities are complex urban spaces that accommodate millions of people. The nature of their inherent duality of the foreground network of city centres linking to each other with the background network of residential spaces provides for opportunities to study how such dynamic urban grids effect social interaction. It is for this reason that green spaces such as parks have been studied in this research, in order to examine how parks, which are pockets of land that are largely not for commercial or residential use, fit within the urban context.

In the attempt to understand the accessibility of the parks, three main questions have been analysed via the means of space syntax as well as demographic data provided by the city census to determine the relationships of the parks within the urban grid as well as to each other. By using integration, choice and connectivity values, it can be suggested that there is a high possibility for people to connect across different neighbourhoods due to the higher integration values at larger radii. However, choice values reveal that there is more of a chance for the possibility of interaction when people are in close proximity to the park, due to the higher choice values at lower radii. Lastly, the combination of connectivity data and demographics suggest that the parks’ spatial configuration does not necessarily effect or reveal characteristics of the neighbourhoods they lie in. Rather, it is the social causes of segregation that contribute
in large part to higher rates of poverty and unemployment of those living near the south and west side parks.

While this study explains certain socio-spatial relations that parks have within the city of Chicago, further studies on park use and accessibility can be conducted in order to determine how best to use green spaces within communities that live below poverty. With many cities now aiming to transform urban grids to be sustainable places for people to live, how parks and other such open spaces are used is crucial when planning neighbourhood and community development.
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PALIMPSEST INDUSTRY: INDUSTRIAL HERITAGE AND INTANGIBLE CULTURAL HERITAGE IN THE CREATIVE CITY

A comparative analysis of the Old Truman Brewery in London and Technopolis in Athens

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ABSTRACT

In the face of growing globalisation, maintaining cultural diversity is considered to be important for the long term resilience of cultural heritage (UNESCO, 2003). An intrinsic part of the latter is industrial heritage, which, together with Hillier’s (2016) notion of creativity as the city’s fourth sustainability, can contribute to building inclusive societies and strengthening the economy. Palimpsest Industry refers to those spatial and social cycles of an industry’s (re)use, which are linked with two fundamental heritage values; the tangible, manifested through the built environment and the intangible, expressed through interactions within a durable network of relations. Intangible Cultural Heritage (ICH) is described as evolving heritage, where tradition and innovation coexist (UNESCO, 2003), while its ‘safeguarding’ is considered crucial in protecting cultural diversity, due to its centrality to the community (Blake, 2009, Jigyasu, 2015).

This paper explores the role of industrial heritage sites and their integration in urban development, through the study of configurational, morphological and perceptual characteristics. For this reason, two industrial heritage schemes are investigated; the Old Truman Brewery in London, UK and Technopolis in Athens, Greece. The study examines those factors present in the urban environment and the syntactic form of each scheme that affect the density of interactions and people’s perceptions of heritage constitution. Along with Space Syntax, on site observations and morphological analysis, mental mapping combined with VGA is also implemented as a tool to bring forth those attributes which constitute living expressions of each site’s legacy.

The findings demonstrate that the studied cases variation is identified to be linked with their spatial configuration and management, but more importantly with their local to global spatial relations in facilitating ‘contacts of the right kind’ (Hillier, 2016) through diffused social networks. It is suggested that enabling socio-spatial diversity and maintaining a life cycle of events are essential for the ‘safeguarding’ of ICH, since together they generate a self-reinforcing process (Gehl, 2011). Finally, this paper highlights the fine balance between conservation of industrial heritage and management of change in facilitating intercultural dialogue, promoting creativity and placing heritage in the heart of community development.

KEYWORDS

Industrial heritage, intangible cultural heritage, creativity, urban morphology, mental maps
1. INTRODUCTION

*Palimpsest*, stemming from *pālin* (again) and *psēn* (to scrape), refers to “something that has changed over time and shows evidence of that change” (Webster, 2006). In the industrial heritage context, it is used to refer to those spatial and social cycles of an industry’s (re)use; as a layering of multiple activities and cultures that unfold within the same place over time. The elements that survive through time are physical (tangible), such as building shells, redundant machinery, but also non-physical (intangible) ones, such as traditional crafts, knowledge systems and values (UNESCO, 2003).

Industrial heritage is regarded as an intrinsic part of cultural heritage and is defined by TICCIH (2003) as, “the remains of industrial culture, which are of historical, technological, social, architectural or scientific value”. It also plays a crucial role in the planning, policy-making and rehabilitation of the remains of deindustrialised sites (ICOMOS/TICCIH, 2014). However, above all, industrial heritage is an interconnected part of cities and their alterations, as it belongs to the urban environment’s past, present and future, but more importantly to people, as it is directly associated with memories, ways of living, traditions and labour movements (Oevermann and Mieg, 2015).

Industrial heritage sites have largely been influenced by the accelerated shift from manufacturing to cultural economies which the late twentieth century economic globalisation brought, and have witnessed an eclectic clustering of urban economic activities and specialized services (Hutton, 2000, p.290). Its effects apart from being social, enabling “knowledge groups” (Hillier, 2016) to come together through specialised knowledge, they were also spatial, reconfiguring urban networks and upgrading the city’s status (Gospodini, 2006, p.314).

With more than half of the world’s population now living in urban areas (United Nations, 2014), the shifting attention to industrial heritage sites is regarded to have a close connection with the search for a personal or collective past and identity (Polyák, 2015). However, in many countries today, they are being identified with promoting activities related to cultural, educational and economic growth, while creative industries are among the most common attractors (Fossa, 2015). What is indeed changing, according to Hillier (2016), is that cities are allowing for creativity by being spatially integrated, due to the scale of networks, their diversity and probabilistic accessibility.

The present research studies the role of industrial heritage sites in the context of Hillier’s (2016) fourth sustainability of the city; creativity, where he proposes that apart from the three city sustainabilities (energy, society and economics) which are the consequences of its spatial form, creativity allows the evolution of both social stability and morphogenesis via social networks. In this respect, the paper aims to analyse those tangible elements manifest in the spatial form of industrial heritage sites and distinguish those intangible attributes which constitute living expressions of their legacy. The main subject of the research is a comparison of two case studies: The Old Truman Brewery located in London, UK and Technopolis situated in Athens, Greece.

Through this comparison, the paper assesses the relationship between the current land uses incorporated in the syntactic form of these complexes and their effect in the density of public interfaces adjacent to them. The evaluation of these activities is crucial not only to capture patterns of spatial occupation and heritage management, but also to assess the synergy between these sites and their urban environment. Moreover, it intends to identify how people perceive intangible cultural heritage (ICH); that is immaterial cultural manifestations of the studied areas and whether this is achieved through a bottom-up or top-down process for each case study respectively. The objective is to provide a valuable understanding of former industrial sites’ role in society and inform an integrated conservation strategy for preserving heritage values, while enabling creativity in the city.
1.1 THE VALUES OF INDUSTRIAL HERITAGE

Heritage has two fundamental values; the tangible, manifested through the built environment and the intangible, a value difficult to measure, expressed through interactions within a durable network of relations. In the heritage context, UNESCO (2003) defines Intangible Cultural Heritage (ICH) as evolving heritage, where tradition and innovation coexist.

Heritage is very often evidenced through tangible assets, such as monuments and buildings, while being assigned hierarchical definitions by committees and organisations, based on specific criteria and strategies. The dominance of this view, as stated by Smith (2006) and Meier (2013), has resulted in the widely-held concept that conservation is about preserving recognized concrete elements, which are later associated with certain heritage values. However, any tangible culture must be sustained by intangible value and vice versa for it to be visualised (Alkymakchy, Ismaeel and Alsoofe, 2012). This explains the reason why the Convention’s definition of ICH includes elements of tangible heritage (objects, artefacts, cultural spaces) in order to maintain cultural diversity (UNESCO, 2003).

Intangible heritage values have always been tied to collective identities; from neighbourhoods to cities and sometimes regions, they have affected how physical, visual and perceived boundaries are formulated (Jigyasu 2015). Considering ICH in the context of industrial heritage is important, because the industry’s evolution apart from producing redundant materials also generates a richness of everyday rituals and ways of life (Alfrey and Putnam, 1992). Despite the prevailing argument that ICH is often more vulnerable than tangible, this is not the case. Tangible heritage in reality requires investment and effort to maintain and adapt it to contemporary use. On the contrary, intangible heritage showcases in the biggest part resilience in structuring identity (Prosper, 2013 cited in Jigyasu, 2015). However, the tangible components often play an irreplaceable role in the manifestation of ICH, as mediators for carrying out collective memories and social activities associated with them (Jigyasu, 2015). Halbwachs (1992) first introduced the term collective memory, stating that memory entails a mesh of external relationships, figures and objects which embody the past. A close link with Bourdieus’ (1986) ‘social capital’ can be identified, since it is in this sense that our individual memory places itself in the set of actual or virtual links that illustrate interactions within a durable network of relationships. Therefore, ICH represents a kind of ‘recycling’ process (Skounti, 2009, p.76); recycling cultural facts and collective memories which become heritage.

This re-theorisation of heritage according to Blake (2009) has turned ICH preservation into an even more complex and political question, especially when considered in response to UNESCO’s Convention (2003) for ‘safeguarding’. Safeguarding is viewed as an important step in protecting cultural diversity and according to Blake (2009) and Jigyasu (2015), priority should be given to the local community, for ensuring its continuing maintenance, transmission and viability. However, there has been criticism (Smith, 2006, Hafstein, 2009, Smith and Akagawa 2009, Taylor, 2016) that the system of heritage is structured on (re)creating a system of inclusion and exclusion. Smith (2006) claims that heritage values are associated with power relations and with the power to qualify and disqualify cultures. Taylor (2016, p.44) also questions the safeguarding of ICH as framed by UNESCO and argues that the act of ‘heritagization’ is a contradictory process, since it places emphasis on the simultaneous (re)production of both cultural groups and “a universalist standardization of culture” with regards to social organisation. She underlines that “rather than preserving, the task seems to be reworking traditional practices” (Taylor, 2016, p.32). This debate stresses the role of ICH in shaping local, regional and even national identities (Blake, 2009, Skounti, 2009).

In an attempt to provide an integrative understanding of industrial heritage role in relation to urban development and creativity, this paper relates the use of space syntax techniques in urban studies with architectural morphology and cognitive mental maps. It is argued here that when both values of heritage are evaluated, they can inform more effectively a socio-cultural and economic strategy for preserving and adapting them.
2. DATASETS AND METHODS

Key to choosing the case studies were their urban transformations resemblance (Hanson, 2000); that is their spatial, social and historical evolution over time set in different cultural backgrounds. More specifically, both of them present similarities in terms of size, architectural morphology, building typology and more importantly, neighbourhood evolution within each city. In response to the heritage values stemming from the varying social background and geographical location, special reference is also made to the differences regarding the present urban environment and on-site heritage management.

2.1 THE OLD TRUMAN BREWERY, LONDON, UK

The Old Truman Brewery located in the Spitalfields ward, is part of the Tower Hamlets Borough and covers 36,500 square meters on both sides of Brick Lane. The area contains some of the most historically and architecturally significant buildings in the Borough and has a cultural legacy of three successive immigrant groups (London Borough of Tower Hamlets, 2009). The brewing industry was active in the area since 1666; it expanded and grew throughout the 19th century, when the brewery became one of the largest in London, and for a brief time the biggest in the world (ibid, 2009). Poor and overcrowded housing surrounded the brewery for many years (Cornell, 2013) and until the early 1970s, industrial development at the Brewery continued, before it closed in 1988. The low-rise buildings along Brick Lane place emphasis on the Christ Church Spitalfields and the Brewery’s Chimney, while stations such as Shoreditch High Street and Liverpool Street, are within a walking distance from the site (Figure 1). From 1991 onwards, it has been redeveloped as a major centre for the creative industries and today it is a family owned and managed site. Together with the famous Brick Lane Market, several markets are also part of the complex (Figure 2).

Figure 1 - Spitalfields landmarks with closest stations (left) and its location within Tower Hamlets (right)
Figure 2 - The Old Truman Brewery today
2.2 TECHNOPOLIS, ATHENS, GREECE

In 1857, the Gasworks Industry, situated southwest of the central Athens sector was established, with the gradual addition of different buildings. The industry's foundation slowly led to the creation of an informal settlement known as Gazohori, which hosted its workforce. The district of ‘Gazi’ took its name from the industry, while its proximity to Pireos street, an important industrial axis, attracted commercial and industrial activities. In the 19th century, Gazi was "a miserable settlement" (Biris, 2005, p.242); it illustrated unemployment, poor living conditions and was inhabited by low income classes. In 1984 the industry terminated its function and as a result the area became degraded. Gazi gradually emerged as an ‘epicentre of recreation and culture’ (Karachalis, 2007), together with the appearance of many freelancers and artists in the area. Since its establishment, the area’s boundaries are considered to be constituted by its four primary traffic arteries, Konstantinoupoleos, Petrou Ralli, Iera Odos and Pireos roads. Gazi contains many distinct landmarks, while its main access point is through 'Keramikos' tube station (Figure 3). From 1986 onwards, the Gasworks Industry became listed and today, the former industrial site known as 'Technopolis', consists of 25,000 square meters (Figure 4). It is managed by the Municipality of Athens and within its grounds a wide variety of cultural and artistic events are hosted throughout the year.

Figure 3 - Gazi landmarks (left) and its location within central Athens sector (right)
Figure 4 - Technopolis today
Methodologically, at the urban scale the structure of both industrial schemes is initially investigated through depthmapX (Varoudis, 2012), using the measures of normalised least angle choice (NACH) and segment angular analysis (NAIN) for different radii (400, 1200, 2000, 4000) to evaluate the industrial complexes’ location within the dual form of the respective city; the foreground morphogenetic network driven by micro-economic activity set into the background network, driven by socio-cultural factors (Hillier, 2016). A patchwork map merging the foreground (angular choice at radius n) and the background (metric mean depth at radius 2000), reveals whether the schemes form part of these networks. In order to understand the processes of current growth and adaptation, a morphological analysis of the urban blocks in terms of land uses is conducted, set within a walking distance radius of approximately 400 meters. Moreover, a frontage/boundaries analysis is carried out supportively with the land use, to study the interface between buildings and public spaces within each scheme.

Central to this research is the micro-functioning of each site; that is the way public spaces between the buildings are used by staff and visitors and how these are managed in accordance to the various events that take place. For the purpose of this analysis, snapshots are used to capture moving and stationary activities of visitors and staff members, record interactions and different activity types. The method was applied at three different time periods during one event weekday/weekend and one non-event weekday for both sites. Moreover, surveys including in total a hundred and four questionnaires and ninety-four mental maps were conducted in the form of short interviews. Two groups of people were approached; the ‘inhabitants’ and ‘visitors’, based on Hillier and Hanson’s (1984) concept. The term ‘inhabitants’ refers to people working in the area, while the term ‘visitors’ to outsiders who do not form frequent encounters. Together with the survey questions, participants were requested to do a quick sketch of each case study, highlighting entering/exit and destination points within the site, path markers which are important along the way and parts in which they feel unprotected. Visibility Graph Analysis (VGA) was applied to a selected mental map sample to reveal their visual integration values (at eye level); the visual distance from all spaces to all others (Hillier, 1996). This analysis is implemented in order to compare the actual visual zones of space with those of the mental one, identify any overlaps that might arise and uncover those elements that affect the perception of each site’s image. Where necessary, the drawings of each complex were adjusted to fit the mental maps created by the participants, which were also simplified and scaled for a comparable analysis.

3. RESULTS

Utilising a diversity of approaches, from configurational to perceptual analysis, this chapter compares the studied cases and presents the findings of the research by synthesising the analysis outcomes under overarching topics.

3.1 EMBEDDEDNESS

A patchwork map merging the foreground (angular choice at radius n) and the background (metric mean depth at radius 2000) networks of both cities; Greater London for the Brewery and Athens Prefecture for Technopolis (Figures 5 a-b), reveals that despite the fact that both cases seem to be towards the edge of the respective city centre, Technopolis appears globally more embedded than the Brewery. However, at the same time it seems to be detached from its urban environment, since the land uses incorporated in its syntactic form are disconnected from its surroundings (Figures 6 a-b). On the contrary, although the Brewery is part of the background network at a global scale, the land uses are embedded within its surroundings (Figures 7 a-b) and hence facilitate ‘contacts of the right kind’ (Hillier, 2016) to emerge.
Figure 5 - Foreground (angular choice radius n) – Background (Mean Metric Depth radius 2000) for (a) the Truman Brewery, (b) Technopolis
Figure 6 - Land uses (a) surrounding Technopolis at 400m radius, (b) within the scheme
Figure 7 - Land uses (a) surrounding the Brewery at 400m radius, (b) within the scheme
The snapshots also support this observation, as it is noticed that compared to Technopolis, the Brewery illustrates more moving, standing and sitting activity throughout most of the days (Figures 8a-b). This means that various user groups have often a reason to be there throughout the year, in contrast to Technopolis, whose visitors choose to go mainly when there is an event happening. However, 86% of the Technopolis inhabitants feel that they belong on site, opposed to 54% of the Brewery's inhabitants. This illustrates that the latter's temporality of the working environment conditions makes it a socially transforming hub. In general the Brewery is depicted to blend in with its surroundings, while Technopolis is represented as a distinct entity.

![Figure 8 - Overall snapshots for (a) the Brewery, (b) Technopolis](image)

Note: Density per square meter differs due to the varying size of the observed areas

3.2 EXPERIENTIAL DIVERSITY AND STRUCTURE

Based on the spatial analysis of the site observations, it is suggested that the clustered arrangement of land use in the studied Spitalfields area, combined with the creative, business-oriented environment of the Brewery complex establishes a corresponding dynamic social structure. The Brewery's inviting character towards the south and central part, together with the proximity of its active frontage entrances (Figure 9a), results in a concentration of activities and in the animation of the public environment; therefore enhancing its spatial-social synergy. It allows groups to move from smaller spaces to larger ones and from their private towards the public zone giving "a greater feeling of security and a stronger sense of belonging to the areas outside the private residence" (Gehl, 2011, p.59).

On the contrary, Technopolis set within a configurationally looser urban environment, while at the same time being closed-off from its surroundings (Figure 9b), constitutes a cultural 'urban island' on its own. Therefore, as far as its social function is concerned, it requires strategic alternatives related with the design of its organisation (Peponis, 1991) to draw people in. The presence of structure in the Spitalfields area evidenced through the land use, illustrates also greater diversity, in contrast to the Gazi area, where a mono-functional layout of restaurants/cafes and residences is distinguished. This explains why different usage patterns are significantly affected by the spatial configuration of each site.
Figure 9 - Frontage analysis for (a) the Brewery, (b) Technopolis
Land use diversity however, is not enough on its own. The questionnaires and mental maps revealed that experiential diversity is also important, since movement patterns, behaviours and human occupation density, all play a crucial role in shaping the urban environment. Furthermore, vacant buildings and empty plots constitute only the 2,05% in comparison with 5% of under construction buildings in the Brewery area, illustrating that the district is an outcome of highly structured sets of socially, economically, culturally and physically related systems in space (Penn et al, 2009). These sets are crucial for generating creativity, as they influence social networks, which are mainly driven by non-spatial factors (Hillier, 2016). Furthermore, the hybridity of many uses embedded in the Brewery, illustrates that enabling contacts between groups definitely constitutes the scheme’s success in structuring and maintaining its development (Allen, 1977, Hillier, 2016). Although Technopolis is globally recognised as a cultural centre, its spaces are not used to its maximum throughout the observed period. The latter, together with its physically closed-off structure intensifies contacts only within existing groups and misses the benefits stemming from diffused networks, such as those evident in the Brewery. Therefore the maintenance of this twofold relation between social advantage and space is crucial for placing heritage in the heart of community development.

3.3 ATMOSPHERE/VIBE

It has been argued by Hillier (1996, p.4) that buildings “constitute the social organisation of everyday life as the spatial configurations of space in which we live and move”. Research carried out for workplace environments (Sailer and Penn, 2009) revealed that organisation and space relate in a very intricate way, as they depend on context, culture and character.

Drawing on this framework, it is argued that the Brewery’s context generates high levels of movement flows throughout all days. More specifically, the retail along Dray Walk stores draws people in, encouraging encounters and attaching a familiar character. This as a result creates co-presence between different users and overall works positively for the ‘movement economy’ (Hillier, 1996) of the place. On the contrary, Technopolis seems to be more static in its interior, due to its cultural use. However, being a landmark for the wider area and for the city itself, it functions as an attractor, aggregating multiple uses along its surrounding streets, which on their turn affect the area’s character.

As far as differences in culture are concerned, it is suggested that the interplay between the material and immaterial elements affects the feeling of belonging and people’s perceptions about each site. More specifically, the enclosed morphology of the Technopolis complex and the concentration of administration/office buildings towards the east part of the site, promotes intimacy in the working environment. On the other hand, the general vibe/diversity of the place is the reason why 46% of the Brewery’s inhabitants feel part of a community. The constant change of activities on site coupled with the diffused working spaces of the Brewery is proposed to be the reason why the general atmosphere dominates above the working environment. This is also evident in the Brewery’s participants’ mental maps, who emphasised activities over the built environment, in contrast with Technopolis’ participants, who featured built landmarks as crucial elements in depicting context and character. Therefore it is proposed that culture, memories and built elements are those attributes associated with Technopolis atmosphere, while creativity and socio-spatial diversity those for the Brewery.

3.4 TRANSITION ZONES AND PERCEPTIONS

Although there are similarities between the studied cases, the existence of recreational, retail and restaurant/cafe facilities within the Brewery appear to be an element of invitation (Gehl, 2011); public space is exposed due to its immediate visibility from the surrounding high-movement streets. The proximity to many local businesses together with the intensification of activities in the Brewery, especially when events and markets co-exist, generates a concentration of multiple user groups. The same happens in Technopolis when festivals and exhibitions take place. However, the concentration of similar user groups in the Brewery, evident through the given descriptions and observations, explains the difference in the individuals’ perceptual
relatedness with each scheme. It is argued that in most contacts a very conscious use of distance is involved, in which individuals may relate to each other in two ways: either by means of closeness (spatiality) or conceptual closeness (transpatiality) (Gehl, 2011, Sailer and Penn, 2009). The latter seems to be the case for the Brewery, while spatiality seems to play a crucial role for drawing people in Technopolis.

In the same way that an individual is linked with a spatial and a conceptual group (Hillier, 2016), distances can also have a conceptual dimension. The mental maps highlight that participants in both schemes, identify points of interest or most frequently visited spaces as being closely linked, while in reality they are located far from each other (Figure 10). Inhabitants of both complexes depicted in detail spaces they occupied, with an exception of those who regularly moved around the site, the majority of whom portrayed a holistic understanding of each site’s layout. On the contrary, most visitors portrayed generically each scheme, by distinguishing landmarks, which acted as reference points for moving around.

Activities also, apart from defining distances between places, seem to outline transition zones. Transition zones are observed to be determined by large open spaces or by elongated narrow ones, where people and activities aggregate, by smaller artefacts, such as installations, and graffiti or even by smells. Brick Lane for example, despite passing through the Brewery’s buildings, is identified as a transition zone, due to its multicultural character and the aggregation of many curry restaurants. On the other hand, due to its large external area, transition zones within Technopolis are characterised by visually integrated spaces outlined by built elements. This is also the case when the analysis is applied to the surrounding public spaces. Although the complex as a whole is visually segregated, the visitor’s mental map highlights it as a visually integrated space, underlying the feeling of protection stemming from the visually enclosing elements of space.

Figure 10 - Visual Integration Analysis for both schemes, comparing the existing area map with the participants’ mental one sample

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3.5 INDUSTRIAL CONSTRUCT INTERFACES AND HERITAGE VALUE

The life cycle of events and activities is proven to be a crucial factor, both in terms of heritage management and in strengthening community participation, but also in ‘safeguarding’ and continuum of ICH. This is particularly evident with the Brewery, which is treated as an evolving and productive site, by enabling opportunities for people to meet organically. Technopolis on the contrary, which is managed more statically, accommodating only periodic events, illustrates an inanimate flow of socioeconomic activity.

In order to ensure integrated development and accommodation of change in industrial sites, attention should be paid to a symbiotic relationship between environment and stakeholders. Both sites and Technopolis in particular, illustrate signs of gentrification, as evidenced through the land use and interviews with participants. In the latter, the residences surrounding and overlooking the industrial site are many, highlighting the fact that stakeholders have already taken advantage of its ‘heritagization’ and reproduction of cultural groups. This is also due to the “musealisation” and “aestheticisation” (Hauser, 2001) transformation strategies that Technopolis has undergone, converting it into an attractive destination throughout day and night. On the contrary, the largest part of the Brewery illustrates a different developmental approach; utilising the building’s shells to their fullest, enables events to take place and facilitates connections between similar social groups. For this reason, ICH is argued to be perceived by the Brewery’s users as a bottom-up process, while for Technopolis as a top-down.

4. CONCLUSIONS

Concluding, this paper investigated the relation between industrial heritage and intangible cultural heritage through a comparison between the Old Truman Brewery in London and Technopolis in Athens. In an attempt to evaluate their spatial performance and highlight those configurational, morphological and perceptual elements that constitute heritage values, an analysis was carried from the urban to the building scale. The aim of the study is to deepen the understanding about industrial heritage sites in initiating future urban development strategies.

Concerning the configuration of the studied cases, it was found that embeddedness, together with local to global spatial relations are essential in creating and sustaining a time-bound productive development. Both case studies highlighted that spatial location and street network global integration play an important role in attracting people, but are not enough on their own, since ‘contacts of the right kind’ (Hillier, 2016) are facilitated through diffused social networks. As far as the synergy between the current land uses incorporated in the form of the case studies and their effect in the density of public interfaces adjacent to them is concerned, it was found that the morphology along with the amount and type of activities which take place on site operate as attractors, creating a dynamic social structure. The land uses, snapshots, questionnaires and mental maps revealed that enabling and maintaining a life cycle of events is crucial for ensuring continuation, since the mix of different user groups together with activities can generate a self-reinforcing process (Gehl, 2011). Moreover, the flexibility in the accommodation of new uses and social groups, achieved through highly structured sets of socially, economically, culturally and physically related systems in space, is suggested to generate experiential diversity.

Additionally, as far as social network facilitation is concerned, the Brewery revealed that the more programmed an industrial site is, the more its heritage tends to be linked with intangible assets, while the more conservative, it tends to be identified with tangible assets, as in Technopolis. The former is important for achieving urban integration, since it is through the existence of conceptual groups that non-local relations can be created (Hillier, 2016). Nevertheless, this does not necessarily mean that spatially induced density is not important. The Brewery, being open and outward-facing to its biggest part, blends-in with its surroundings, whereas Technopolis being enclosed and inward-facing, stands out. Furthermore, an interdisciplinary approach regarding heritage management and community participation seems to affect people's perception of ICH. The adaptation and hybridity of the Brewery's spaces appears to have strengthened intercultural dialogue and cultural diversity, which is argued to be important for the 'safeguarding' of its ICH. In the Brewery, ICH is proposed to have emerged as a bottom-
up process, since it is embraced through the dominating atmosphere/vibe, the socio-spatial diversity and the transpatial relatedness of its users. On the contrary, ICH in Technopolis is suggested to be perceived by both user groups as a top-down process, since the participants’ mental maps highlighted the site as an enclosed entity and placed emphasis on its tangible elements over its activities; denoting the dominance of its “heritagisation” process.

Finally, the present paper has suggested that palimpsest industry can be considered as the integration of multi-layered narratives, user experiences, perceptions and cultures. Finding the balance in conserving and managing existing resources, while enabling a sustainable development, is crucial for the future continuation of industrial heritage sites.

This paper forms part of a larger study carried out through the author’s MSc dissertation. The main limitation of the research was the restricted period provided to gather the necessary data for the analysis; hence the studied cases had to be constrained. Further research on similar sites built in different cultural contexts and using a wider sample of participants is required to fully support the fore mentioned findings. Also, a historic research combining configurational and land use evolution would be of particular interest to investigate sustaining typologies and trade patterns over time that could possible form part of each area’s ICH. Land uses and frontages in a wider area could also be further examined to formulate a holistic image of each district, while snapshots could be carried out systematically for the rest months of the year. Additionally, a quantifiable analysis of the mental maps could also be further examined by correlating the data presented in the maps and the actual structure of each case study. Together with space syntax, this could potentially lead to measuring people’s perception and mapping intangible culture.
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THE EFFECT OF THE STREET NETWORK ON MOVEMENT PATTERNS AND LAND USE IN SMALL CITIES

A comparative study of three 10k cities in Thuringia, Germany

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ABSTRACT

Thuringia - a federal state in Germany - is characterized by a low-density settlement structure with 65% of its urban population living in cities with less than 25,000 inhabitants. In order to develop plans for the future of this region of Germany, it is necessary to understand how such small cities work, and how their spatial structure influences the life of their inhabitants. One crucial aspect thereby is the movement of people that is on the one hand shaped by the urban form, and on the other shapes how spaces are used. For our study, we selected three small cities, having a population of approximately 10,000 inhabitants. In these cities, we collected empirical data describing different modes of movement and the uses of each building in each city. Finally, we investigate the relationship between the empirical data and the configuration of the spatial structure of these cities. The results of this study confirm a relationship between street network configuration, movement, as well as use of commercial space in small cities. Nevertheless, this relationship also has its specificities, in regards to the proximity of spaces on the local level, which needs to be considered in the process of spatial analysis.

KEYWORDS

Small Cities, Movement, Land Use, Metric and Angular Street Network Centrality

1. INTRODUCTION

Despite the globally ongoing urbanization processes resulting in ever growing cities of worldwide importance - so called first-tier cities or global cities (Sassen, 2001) – still the majority of the population worldwide lives in small settlements (tertiary or third-tier cities). In fact, for Germany, a country with an urbanization rate of 75%, almost half of its population (45.8%) is living in cities with less than 25,000 inhabitants (see table 1). Thus, these small urban settlements have a high influence on the countries social, economic and ecological well-being. However, despite their importance, small cities have been largely ignored by urban theorists, leading to fact that planning strategies for the future of such cities are widely missing (Bell & Jayne, 2009).
In order to support planning for the future of small cities it is necessary to understand how these cities work (in particular, how they influence the life of their inhabitants). One crucial aspect thereby is the physical spatial structure (urban form / morphology) of these cities since this is once built hard to change and thus has a long-lasting impact on the city and its inhabitants. The spatial structure of a city can be categorized into three layers: streets, plots and buildings (Conzen, 1960). These three layers are strongly interdependent, whereby streets can be seen as the superior structuring element of the urban form (Marshall, 2005). For example, the shape of buildings restricts the number of users and possible usages, and plots define the maximum size of buildings, whereas streets define the maximum size of plots and restrict the possibilities for plot division. Furthermore, streets largely determine the paths that are possible to take to get from one building to another and thus also shape the movement of people within the city. This in turn is said to influence how public spaces and buildings are used (Hillier, 1996). Thus, the street network can be seen as a main driver for urban life. This has been shown in many cities worldwide. According to Penn (2001) summarizing the decades of space syntax research between 60-80% of the variance in movement rates can be explained by the geometry of the street network. However, the cases considered thereby are mostly large cities or quarters in large cities. Since the here regarded small cities (also referred to as third-tier cities) are an urban category on its own, it seems hardly possible to adapt planning strategies of second- or first-tier cities to them (Siegel & Waxman, 2001). Thus, the interesting question that arises for us is, if these small cities work spatially similar to the large cities, where a strong relationship between the street network and movement and land use has been found.

Nevertheless, until now, only few studies exist, in which the influence of the street network on urban life has been quantitatively investigated in small cities. Hillier & Hanson (1984) studied small villages in southern France and northern England, whereas these studies remained mainly morphological (discovering the so called “beady ring”-structure of such small settlements). Recently, some relations between the centrality of streets and the distribution of important public services were sketched. Medeiros & Hollanda (2005) found in a comparative study of Brazilian urban layouts that small cities exhibit a higher degree of integration (means that streets and consequently their inhabitants are visually closer). Al-Gatham (2012) studies urban villages in Bahrain (in particular the movement patterns of different demographic groups), however these villages are part of a larger urban structure, making it difficult to relate their results to the small solitary cities we are interested in. Karimi & Vaughan (2014) conducted a space syntax analysis and movement counting for new towns in England (with a population of around 50,000 to 80,000). The relationships between movement rates and space syntax measurements were described qualitatively, stating that most of the people walk close to or inside shopping centres and not along the spatially most integrated streets.

In the following paper, we look at the effect of the street network on movement patterns and land use in three small cities (around 10,000 inhabitants) in Thuringia. Thuringia (a federal state in Germany) is characterized by a low-density settlement structure with more than half of its urban population (~65%) living in cities with less than 25,000 inhabitants), thus the choice of our city size fairly represents the average Thuringian urban landscape.

2. THREE SMALL CITIES AND THEIR DATA

This section briefly describes the three cities and the process we used for collecting empirical data (movement and land use) and the methods used to calculate street network measures. The three cities that we used for our study are Hildburghausen, Waltershausen and Zella-Mehlis. They have almost the same number of inhabitants (around 10,000 or 10K Cities) and are of similar size regarding the built plots (3.8 sq km). However, they differ morphologically due to their geographical situation and their historic development. The plans of these cities are shown in figure 1.

Hildburghausen (in the following referred to as HH), a city in the south of Thuringia (close to the Bavarian border), started as a settlement in the 9th century and got city-rights in the 13th century. The number of inhabitants grew from mid of the 19. century from ca. 5,000 to ca. 12,000 inhabitants in the 1980s. From then on the population slightly shrank to ca. 10,100 today. HH is located in a valley directly at a river (Werra). This river cuts the city into a northern part (in which the historical core is located) and a southern part (which consists on the one hand of an industry park and a quarter of detached houses).

Waltershausen (WH), a city in the mid-west of Thuringia (close to an important motorway A4 and the capital Erfurt), was firstly mentioned in the beginning of the 13th century. Its population grew from mid of 19. century from about 4,000 inhabitants to 15,000 in the 1950s. It shrank to approximately 10,300 till today. WH is located on a rather flat terrain. However, a hill in the south of the city restricted city growth in this direction. Thus, the historical core is nowadays located at the edge of the city.

Zella-Mehlis (ZM) is a city in the Thuringian forest, formerly being two villages (Zella and Mehlis) founded in the 12th resp. 13th century. They were merged to one city in 1919. ZM reached 17,000 inhabitants in the 1950s, from then on its population shrank to 10,600 inhabitants in 2015'. ZM is surrounded by hills and exhibits a hill in its geometrical centre, causing this part of the city to be unbuilt.

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Figure 1 - Figure Ground Plans of the three cities with historic centres marked with a red dot (from left to right: Hildburghausen, Waltershausen, Zella-Mehlis)

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2 This number remained almost stable since 2011
Concerning the building types all three cities exhibit a historical part (with densely packed row houses), condominium housing districts, built in the 1960s to 1980s, districts with detached houses (mainly one-family) and industrial zones. In HB and in WH the industrial zones are located at the edge of the city (in the east and in the south-east in HB and in the north in WH). In ZM industrial buildings - from the late 19. Century- are located in between the formerly two villages. Today there is a large industrial zone between ZM and the neighbouring city Suhl (this was excluded in our urban model, since it is not directly connected to the city itself separated by the railways).

Regarding the morphology of the three cities, HH exhibits the most compact city shape (almost circular) with the historic core in the geometric centre, while WH has an almost rectangular shape rotated towards the northwest with its historic core at the western city border (only followed by a suburban one-family district). Finally, ZM exhibits two historical centres due to the fact that this city emerged from two formerly separate villages (as shown with the red dot in Figure 1).

2.1 DATA COLLECTION

The city models (street network, plots, and building footprints) were created based on the official data provided by the federal state3. The data for movement and land use was collected in October 2016 (with students in the course of a seminar). The number of pedestrians passing was categorized into three age groups (children, adults, elderly) and the number of vehicles in two types (bicycles or cars). The movement direction and how many times each user passed, was not considered. The counting was conducted twice, once in the morning (from 10:00 – 11:00) and once in the afternoon (14:00-15:00). Each counting took 15 minutes. The usage as well as the building height (number of storeys) was recorded. Regarding the building usage, we prepared a list of typical usages (as residential, trade, services, education, industrial or vacant). The data for movement and land use was collected in October 2016 (with students in the course of a seminar on computational urban analysis).

The counting and mapping was done manually on paper and later digitalized. For this purpose, we developed a tool (for Rhinoceros3D 4 / Grasshopper5) that enables to flexibly visualize and analyse spatial data. In Figure 2 the results of the counting and land-use mapping are shown. In all three cities, the old centres exhibit high pedestrian flow specially near the market square, almost half of the passing pedestrians were old people, most of the main roads showed an increase in passing vehicles, and almost 90% of them were cars, Commercial buildings cluster in the old centres, and there is a noticeable amount of vacant spaces in each city. In Figure 2 the results of the counting and land-use mapping are shown. It can be seen that in all three cities the old centres exhibit high pedestrian flow specially near the market square, almost half of the passing pedestrians were old people, most of the main roads showed an increase in passing vehicles, and almost 90% of them were cars. Commercial buildings cluster in the old centres, and there is a noticeable amount of vacant spaces in each city.
Figure 2 - Mapping of the data collected in the three cities: first two rows show mapping of pedestrian and vehicle movement with pie charts, whereby the diameter represents the total number, and the sections of the pie represent the ratio of different users (elderly, adults, children for pedestrians and cars and bicycles for vehicles). The last two rows display the locations of both commercial and vacant buildings.
2.2 STREET NETWORK ANALYSIS

Street Network properties describe how streets relate to other streets. Therefore, typical graph measures such as Closeness Centrality (Integration) or Betweenness Centrality (Choice) are used. Whereas the former indicates how close a street is to other streets, the latter indicates how often a street is passed on the shortest paths to other streets. The distance between streets can thereby be measured metrically (physical / walking distance) as well as by angles (which is said to be more related to psychological distance). The latter is usually used in Space Syntax, claiming that this is more appropriate for predicting movement patterns (Hillier & Iida, 2005; Turner and Dalton, 2005; Varoudis et al., 2014) and the subsequently following land use. However, studies exist, show that network centralities based on metric distance also have a significant correlation to the distribution of commercial uses (Sevtsuk, 2010), and empirical research shows that people are neither choosing their ways purely on basis of Euclidian distance (Golledge, 1999; Mallot & Basten, 2009), nor exclusively on the basis of cognitive effort (Li & Tsukaguchi, 2005; Takeuchi, 1977). Therefore, in our study we use both, angular and metric distance, in order to understand which is more suitable for our small towns.

For conducting both types of analyses we used the segment map (Turner, 2001) as a model for representing the street network. The segment maps of all three cities were drawn manually. Therefore, we adjusted the road-centre-line-based network of the official data in order to respect the visual connections from one segment to the other. For example, T-intersections that are close to each other have been joined to an X-intersection to avoid two 90° turns where in reality there is almost no turn necessary. Furthermore, additional segment for crossing public squares have been inserted.

The parameters of the centrality measure have influence on the results, since it mathematically defines the travel distance which people are willing to overcome. These parameters are described through the proximal distance, and angular distance and how the network is mapped, in different radii. We defined our radii starting from at 200 m until 2000 meters (R200, 300, 400, 500, 600, 800, 1000, 1200, 1600, 2000 and radius n). Although there are no clear boundaries between these scales (Vale & Pereira, 2016), we here refer to a local scale from 200 up to ~600 m and the global scale from 2000 m and larger6.

The measures were calculated in DepthmapX7, and then exported to our analysis toolbox for further analysis and visualisation. In Figure 3 some of the analysis results for angular analysis are shown (Choice and Integration, each R300 and Rn). The results for metric analysis can be found in the appendix. The results intuitively coincide with the structure of the cities: the main roads are highlighted in the global centralities. The centre of the cities can be identified on the local scale. Here it should be noted, that also the two separate centres of ZM (formerly two villages) are well visible.

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6 It should be noted, that for global scale radius 2000 m and radius n will be treated similarly, since in our small cities the longest distance from one end to the other is not larger than 3500m, the analysis results - Pearson correlation coefficient- in radii larger than 2000m correlate very strongly to the results with Radius n (r > 0.9).

7 https://varoudis.github.io/depthmapX/
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Figure 3 - Space Syntax Accessibility Measures (Angular only) for the three cities
2.3 MAPPING LAND USE TO STREET SEGMENTS

To correlate street network properties to empirical data, the data needed to be mapped to the street segments. In the case of movement counting, this is rather simple, because the countings were conducted in a certain street segment. In the case of land uses a mapping is necessary, because these were recorded for each building and not per street segment. E.g. we want to know how many buildings with commercial use are assigned to a street segment. Thereby, however, it is not useful to only map all the buildings that are directly attached to the street segment, because the number of buildings is highly dependent on the length of the segment. Since street network properties are not dependent on the length of a segment (also very short segments can exhibit a high closeness or betweenness centrality) a different kind of mapping is necessary.

In this paper, we propose a method for mapping buildings to street segments based on visibility. Thereby we search for buildings visible to a segment within a certain range. As a range we use the maximum distance for a pedestrian to well recognize an object (e.g. a sign that indicates the use of the building). Here we use 100 meter (according to Gehl & Svarre, 2013). The method works as follows: First, we divided the segment to a sequence of points in a distance of appr. 5 meters. From each point we shoot a perpendicular ray (100 m long). At the segment ends, we shoot 180° isovist rays away from the segment. If a rays hits a building, that the exhibits a certain use (e.g. commercial), than this building is assigned to the segment. In Figure 4 this is exemplified: the red- and blue coloured buildings are commercially used, grey buildings exhibit other uses. Commercial buildings within the visible range (colored in blue) are assigned to the segment. The building colored in red, (although the also hosts commercial uses) fall outside the visibility range and are therefore not considered for this segment.

![Figure 4 - Using rays for mapping building uses to a segment](image)

After the buildings are assigned to a street segment, the number of buildings as well as the floor area of the buildings with a certain use can be computed for each segment. To avoid the influence of the street length on the results, the data was normalized (divided by the length of the segment).
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3. CORRELATIONS

In the following we look at the relationships between street network and empirical data. Therefore, we tested the relationships between both dependent and independent variables using Pearson’s correlation coefficient r. This measure not only shows the strength of the relationship but also the direction – positive or negative – of the relation. For our statistical analysis process, we used a toolbox for statistical analysis for Grasshopper, based on R\textsuperscript{8} (Abdulmawla et al., 2017).

From our empirical data, we selected for the movement countings both the aggregated pedestrians and the aggregated vehicles. For the land use we selected commercially used and vacant buildings. These - compared to other usages such as schools, hospitals, governmental (whose position is most often decided top down) - typically developed other time (bottom up, regarding the individual location qualities). Thus, we assume that buildings with commercial use are positioned in commercially attractive locations (with a high amount of pedestrian traffic) and the presence of vacant houses reflects unattractive locations (not well accessible, or no pedestrians). As values, we use the number and area of commercially used and vacant buildings. Both values are interesting, because they indicate different kinds of types of a certain building, which might also be addressed to different spatial locations. E.g. we assume many small commercial buildings in the spatially more integrated parts of the city and a fewer number (however with a large building footprint) at the more segregated parts.

To summarize, in our statistical analysis we tested the relation between the six empirical datasets (pedestrian and vehicle movement; number and area of commercial and vacant buildings) and four centrality measures (angular choice and integration and metric choice

and integration) in different radii starting at 200 m up to Rn. The outputs of the correlation process are matrices of values between -1 and 1. In order to speed up both the reading and the comparison of these matrices, the data was visualized using R heatmap as shown in Fehler! Es wurde kein Textmarkenname vergeben. figure 6 and 7. The red colours show high positive correlation and the blue shows high negative correlations. The correlations were clustered into five categories (strong and medium for both positive and negative and weak for no relation).

3.1 AGGREGATED DATASET (ALL THREE CITIES AT ONCE)

To get a general picture of the relation between street network and movement and land use in small cities we first take a look at the correlations in an aggregated dataset of all three cities. The heatmap is shown in Figure 6. When we look at the relation between movement and street network, we can see a medium positive correlation between pedestrian movement to both global and local angular Choice and Integration peaking at local radii (R300 to R800 with r~ .55 to .6), to local metric choice (R200 to R800 with r~ .39 to .53), as well as to global metric integration (R8000 to R2000 with r~ .34 to .46). Regarding vehicular movement, there is a medium positive correlation between the number of vehicles and global angular choice (Rn with r = .38).

When we look at the relation between commercial buildings and street network, there is a strong positive correlation between number of buildings with commercial uses to local angular and metric choice (R200-R600 with r~ .63 to .82, with a peak at radius 300m), a medium positive correlation to angular integration across all radii (r~ .42 to .65, with a peak at R400, r = .65), as well as metric integration (above R600 with r~ .33 to .42). Furthermore, there is a medium correlation between the area of commercial use and global metric integration (Rn with r = .42).

Regarding the relation between vacant buildings street network, there are only weak correlations, peaking at global radii (r ~ 0.2-0.27).

The correlations found in the aggregated dataset, coincides with body of research on space syntax: it shows that places with high local accessibility also have higher local pedestrian movement, followed by commercial activities. Although low, there is a trend that vehicle movement correlates stronger to global radii, followed by the size of commercial buildings.


10 Five correlations categories:
- Between -1.00 to -0.60 strong negative correlation
- Between -0.59 to -0.30 medium negative correlation
- Between -0.29 to 0.29 weak to almost no correlation
- Between 0.30 to 0.59 medium positive correlation
- Between 0.60 to 1.00 strong positive correlation
3.2 COMPARING THE THREE CITIES

When looking into the cities individually, we can see some notable deviations from the average correlation matrix presented above. Therefore, we created heatmaps for each city (Figure 7). In this section, we look at the deviations exhibited compared to the aggregated dataset and try to formulate hypotheses for the reasons of these deviations based on our experiences from the field trip.

3.3 MOVEMENT

In HH there is an increase to high positive correlation between number of pedestrian movement to both Angular Choice & Integration (all radii with \( r \approx 0.60 \) to \( 0.83 \), with a peak at \( r = 300m \)), to local Metric Choice (\( R_{200} \) to \( R_{500} \) with \( r \approx 0.63 \) to \( 0.76 \), with a peak at \( r = 300m \)). This coincides with our experience of HH as the one of the three cities with the most lively city centre. Furthermore, in HH we can observe an increase to medium negative correlation between vehicle movement and local Angular & Metric Choice (\( R_{200} \) to \( R_{300} \) with \( r \approx 0.37 \) to \( 0.4 \), with a peak at \( r = 200m \)). This might be due to the location of market square where there are street segments for pedestrian use only.

In WH there is also an increase to high correlation between pedestrian movement and both local Angular and Metric Choice (\( R_{300} \) to \( R_{800} \) with \( r \approx 0.58 \) to \( 0.83 \), with a peak at \( r = 500m \)), the correlation to both Metric and Angular Integration are similar to the aggregated dataset.

Opposite to HH and WH, in ZM there is a drop to almost no correlation between pedestrian movement and both local Angular and Metric Choice. There is a medium positive correlation to Angular Integration \( R_{500} \) to \( R_{800} \), \( r \approx 0.34 \), medium positive correlation to Metric Integration (\( R_{1200} \) to \( R_{1600} \), \( r \approx 0.47 \)). This low correlation might be due to the dispersed city structure (formerly two villages), whose global structure does not support the local centres (see figure 3). Regarding vehicle count there is an increase in medium positive correlation of vehicle count to both Angular Choice (\( R_n, r = 0.53 \)) and Metric Choice (\( R_n, r = 0.35 \)).

3.4 COMMERCIAL BUILDINGS

In HH there is an increase to a high positive correlation between the number of commercial buildings to Angular Choice (All Radii with \( r \approx 0.61 \) to \( 0.91 \), with a peak at \( r = 300m \)), to global Angular Integration (\( R_{200} \) to \( R_{600} \) with \( r \approx 0.70 \) to \( 0.80 \), and \( R_{1600} \) to \( R_{2000} \), \( r \approx 0.65 \)), to local Metric Choice (\( R_{200} \) to \( R_{500} \) with \( r \approx 0.6 \) to \( 0.76 \), with a peak at \( r = 300m \)), as well as a medium correlation to global Metric Integration (\( R_n, r = 0.56 \)). There is another increase to medium positive correlation between the area of commercial buildings to both Angular Choice & Integration at all radii (\( r \approx 0.42 \) to \( 0.6 \), with a peak at around \( r = 300 m \) to \( 600 m \)) and to local Metric Choice (\( R_{200} \) to \( R_{500} \) with \( r \approx 0.42 \) to \( 0.55 \)).

WH has almost identical correlations as the aggregated dataset, except a small increase in the medium positive correlation between number of commercial buildings and Metric Integration (\( R_{500} \) to \( R_n, r \approx 0.4 \) to \( 0.55 \)) and an increase to medium correlation between the area of commercial buildings and local Angular Choice (\( R_{300} \) to \( R_{600} \), \( r \approx 0.3 \) to \( 0.37 \)).

ZM exhibits an increase to medium positive correlation between number of commercial buildings and Metric Integration (\( R_{200}, r = 0.53 \), \( R_{600}, r = 0.41 \) and \( R_{1200}, r = 0.51 \), an increase to medium negative correlation between global Metric Integration and area of commercial buildings (\( R_{1000} \) to \( R_{1600} \) with \( r \approx -0.30 \) to \( -0.39 \)). This confirms with the fact that the shopping centres are located at the edges of the city.

3.5 VACANT BUILDINGS

Regarding vacant buildings in HH there is only an increase to medium positive correlation to local Metric Integration (\( R_{200}, r = 0.50 \)) and global Metric Choice (\( R_{1000} \) to \( R_{1200}, r = 0.31 \)).

In WH, there is a general increase to medium positive correlation between the number of vacant buildings to both Angular Choice & Integration and Metric Integration at all radii except \( R_{200} \) in
Choice (with $r \approx 0.34$ to $0.63$), to global Metric Integration ($R_{1000}$ to $R_{n}$, $r \approx 0.33$ to $0.44$). Regarding the area of vacant buildings there is an increase to medium correlation between both Angular & Metric Choice ($R_{200}$ to $R_{2000}$ with $r \approx 0.32$ to $0.63$), to Angular Integration at all radii, as well as, to Metric Integration at various radii ($R_{600}$, $r = 0.34$, $R_{1200}$ to $R_{n}$, $r \approx 0.32$ to $0.52$).

ZM exhibits an increase to medium negative correlation between number and area of vacant buildings to global Metric Integration ($R_{1000}$ to $R_{1600}$ with $r \approx -0.33$ to $-0.42$), to local Metric Choice ($R_{500}$ to $R_{600}$, $r \approx -0.30$ to $-0.33$), as well as, an increase to medium positive correlation between the area of vacant buildings and local Metric Integration ($R_{200}$, $r = 0.32$).

Figure 7 - Heatmaps showing correlations ($r$) between street network measurements and movement / land use

Hildburghausen (HH)

Waltershausen (WH)

Zella-Mehlis (ZM)
4. CONCLUSION & OUTLOOK

Small cities are an urban category in its own and therefore need special consideration in the conception of planning strategies. In this paper, we studied the relationship between the street network and the movement patterns and land use in small cities. We correlated countings of pedestrians and vehicles, as well as the number and area of commercial and vacant buildings to Angular and Metric Choice and Integration. When looking at the aggregated dataset of all the three cities, we could find a high correlation between both pedestrian movement and commercial activities to the local centrality measures. However, when look at each city individually we found significant deviations, which might be due to each cities particularities. However, what remained almost constant in all three cities was a high correlation between the number of commercially used buildings and local Angular Choice.

Furthermore, we found that the relation between spatial configuration and how people move and land use is highly dependent on the analysis radius. The strongest correlations could been found at relatively small radii (200 – 300m). This contrasts with previous studies conducted in cities of larger size (where pedestrian movement it is often referred to at radii of 600 m to 1000 m). Which indicates that the pedestrian movement might be affected by the scale of the city (the willingness to walk might increase with city size).

While in this paper we only could give a small insight into the role of the street network on the functioning of small cities, we hope to, in the future, gain deeper insights on this topic. Therefore, we will on the one hand look closer at the reasons for the differences between the cities. On the other hand, we will include other spatial metrics (e.g. density, plot sizes, origin-destination based path models).
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APPENDIX

Figure 9 - Space Syntax Accessibility Measures (Metric only) for the three cities
ENCOUNTER AND ITS CONFIGURATIONAL LOGIC:
Understanding spatiotemporal co-presence with road network and social media check-in data

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ABSTRACT
Public space facilitates the social interaction between people. It is widely accepted that the connection between spaces creates the possibility of the mutual visibility between people. The relationship between spatial configuration and the spatiotemporal encounters, however, has rarely been investigated explicitly in empirical cases. The focus of this study is two folded: firstly, it examines the way to measure spatiotemporal encounters between different groups of people based on their mobility records; secondly, it investigates how the design of the built environment contributes to physical co-presence on spatial and temporal dimensions. Using ubiquitous individual social media check-in data in Central Shanghai, China, this study proposes a framework for quantifying physical face-to-face co-presence patterns between the defined local random walkers and the remote visitors across time in every street. In the introduced People-Space-Time (PST) model, social capital is conceptualised as an integration among social difference, spatial distance (metric and geometrical distance) and time distance. The reliability of the applied data and the effectiveness of the introduced methods are validated by the investigations of the scaling nature of the extracted mobility patterns and the correlation between the outputs and surveyed data. The produced spatiotemporal patterns of face-to-face co-presence reveal that city centres and the large-scale urban complexes (e.g., transport hubs, shopping malls, stadiums, etc.) are ideal places for people to encounter. The results of the regression analyses demonstrate that spatial and functional centrality measures are significant variables for predicting spatiotemporal co-presence in streets, but in which the functional centrality structures maintain a higher standard of explanatory power than the spatial network. The temporal complexity of the co-presence is revealed by the temporally shifting performance of the integrated regression models across time. The findings in this study yield that it is the spatio-functional interaction influencing spatiotemporal variation of the physical encounter between people, and reclaim the necessity of adding fine-scale land-use patterns in the traditional configurational analysis for deeply understanding the social processes with urban big data in the contemporary digitalised cities.
KEYWORDS
Co-presence, spatial configuration, spatio-functional interaction, social media check-in, space syntax

1. INTRODUCTION

The city is a complex system for interaction. In geography, the linkage between the theory of spatial from and other temporal process has been explored theoretically and empirically (Harvey 1969). Geographical landscape shapes the spatial generator for the (re)production of the temporal process from place to place. Such an idea has formed the theoretical foundation for configurational studies focusing on the interrelation between the spatial configuration and the movement. The concept of ‘co-presence’ in space syntax theory has been argued as a by-product of the organisation of the built environment that often manifests itself in people’s ‘movement’ due to the fact that connections between spaces create the possibility of the mutual visibility between people (Hiller and Hanson 1989). By combining the concept of ‘co-presence’ in space syntax and social science, Marcus (2010) provided the possibility of liking the so-called spatial capital with social capital. Some studies have been conducted to prove the interdependency between them, but the relationship between the spatial configuration and spatiotemporal encounter patterns has rarely been investigated explicitly with the city-wide observation in the empirical studies.

The main scope of this study is to empirically explore the extent to which the spatial design influences the physical face-to-face interaction between different groups of people, the social media users more precisely, in the contemporary digitalised society. Two types of people are focused in this study: the random walkers who frequently move in a space, and the remote visitors who only visit the space irregularly. The co-presence between these two groups is quantified as an interplay between various social capital, including social difference, spatial distance (metric and geometric distance) and the time cost. Relevant results are mapped in street segments to illustrate fine-resolution distributions of the co-presence intensity. Meanwhile, streets are indexed by quantifying their spatial and function contexts to reflect the urban spatial and functional centrality structures. A multivariate regression is used in this research to explore the explanatory power of the spatial and functional centrality variables for the spatiotemporal co-presence intensities in streets. The remainder of this research is structured as follows. Section 2 introduces the background of this research followed by the descriptions of the methodology as well as data. Section 5 documented the empirical results in detail. At last, section 6 concludes the papers with a summary and a discussion on the further steps.

2. BACKGROUND

A society is a system of social interaction, and co-presence is one of the essential conditions for the occurrence of social interaction (Giddens 1984). Its definitions are ambiguous owing to the variation of theories, methodologies, and spatial scales for analysis. It can also be defined as a sense of co-existence between people in their virtual communications via various sharing behaviours, such as photo sharing or social media interaction (Ito and Okabe 2005). In social geography, co-presence can be adequately understood from its antithesis - segregation - which describes the passive separation of certain group(s) of people from other population (Massey and Denton 1993). Owing to its natural linkage to the demographic characteristics of the population, segregation is conventionally explored in the resolution of areas/districts that are artificially defined for spatial statistics, e.g., census units or administrative boundaries (e.g., Ernest Burgess 1928; Wong 1993). The spatial dimension of segregation at the intra-urban scale has been argued as also being critical (O’Sullivan and Wong 2007) and many methods have been developed to model the potential spatial interaction across the activity space, including k-nearest neighbouring aggregation (Osth et al. 2014), kernel density estimation (O’Sullivan and Wong 2007), activity-based modelling (Wong and Shaw 2011), etc. Although the spatial distance between analysis units has been considered in these models, the effects of urban design have rarely been involved in relevant studies.
Physical co-presence, face-to-face encounters, in particular, reflects urban vitality in public space and its publicness (Mitchell 1995). In configurational studies, co-presence is a fundamental concept binding spatial connectivity to urban movement (Peponis et al. 1997), which has been verified by experiments with an agent-based simulation (Penn and Turner 2001). Recently, Marcus (2007; 2010) has reconceptualised spatial centrality as ‘spatial capital’ and emphasised its quintessence for understanding social performativity. Furthermore, geographical accessibility metrics for different sections of the population and job opportunities through spatial networks were adopted to estimate co-presence patterns (Legeby 2011; 2013; Marcus and Legeby 2012). These efforts have suggested that structural centralities are capable of affecting the co-presence patterns. Nevertheless, these studies were basically on the basis of static spatial data without proper consideration of the dynamics of people’s mobility patterns. Consequently, the interdependency between the spatial configuration and spatiotemporal encounters has rarely been investigated explicitly in these empirical cases.

Co-presence is also a critical dimension in mobility patterns indicating that social interaction is associated with people’s travel choices. This idea has been widely accepted in transport geography with a focus on the collective results of many individual trips (Kenyon et al. 2002; Gonzalez et al. 2008). Related studies have highlighted the importance of the temporal processes of physical encounters. Some attempts based on human contact networks have been conducted (e.g., Stehlé et al. 2011; Isella et al. 2011). With the help of Bluetooth sensors, Kostakos et al. (2010) have clarified the spatiotemporal patterns of mobility, presence and encounters. Sun et al. (2013) evaluate repeated face-to-face encounters using a time-resolved social encounter network on public buses. However, the datasets adopted in these studies are either embedded in limited samples within small areas or are constrained to one type of transport, thereby failing to produce fine-scaled physical co-presence patterns covering the large landscape.

3. THE METHOD

3.1 THE FRAMEWORK

The framework of this study is shown in Figure 1. There are four modules including (a) data processing, (b) measuring co-presence patterns, (c) measuring centralities and (d) exploring the configurational logic of co-presence. In the first module, required datasets are mined and then processed for abstracting the most reliable information for the initial data gathered from the open data resources. For instance, place-based check-ins records (check-ined Points-of-interest (POIs)) are spatially assigned to their nearest street segments, and individual check-in records should be aggregated to trips and filtered by removing the invalid information for making them as an exact description of the mobility patterns. In the next module, trajectory patterns obtained from the social media data are applied to compute the presence and co-presence patterns across time with the street network data. Simultaneously, social groups of people are identified according to their travelling behaviours that are recorded in mobility patterns. The physical presence of people based on metric distance and the angular distance are combined to take into account the influence of the public space on the patterns of the face-to-face encounters. The presences of people in different groups across time are joined to capture spatiotemporal patterns of their co-presence.
In module (c), the street network and placed-based check-ins data are employed in the calculations of the spatial and functional centrality indices. At the last step, computed co-presence patterns and centrality patterns in streets are used as the dependent variables and the independent factors in regression models, respectively. The multivariate linear regression model is adopted to capture the impact of urban form and functions on the hourly varying co-presence intensity patterns. By doing so, this study investigates the spatial logic of the temporal significance of physical co-presence and its inherent differentiation from street to street.

3.2 MEASURING THE PHYSICAL CO-PRESENCE

3.2.1 THE PEOPLE-SPACE-TIME (PST) MODEL

Co-presence is a multidimensional concept reflecting the interplay among different types of social capital. This study proposes an integrated model in which these interactions between various forms of social capital can be comprehensively addressed. These interactions can be summarised as the social capital of people, space and time, which have been acknowledged to be essential for the creation of social ties (Crandall et al. 2010). Social capital for people denotes social difference between people, which can be captured by their demographic features, such as social classes, educational backgrounds, etc. Social difference denotes the fundamental cost of human interaction because it captures the internal variance between people. Social capital in space and social capital in time, on the other hand, are the external conditions for people’s interaction.
The social capital in space, or ‘spatial capital’ can be reflected by the spatial cost that people need to overcome in their trips to see one another. There are two types of spatial capital: metric distance, which reflects the energy cost for people to travel and encounter; the other is angular distance, which captures the cognitive efforts that directly impact the mutual visibility between people. The more two individuals are metrically and geometrically proximal to one another, the more likely they will see one another in the space. Additionally, time constraints are also very important since people could hardly to encounter one another if they are present at the same place at different times.

In Figure 2a, the hypothesised moving trajectories of three users are mapped, and two co-presence cylinders are used to capture the co-presence between them occurring at different time periods. Cylinders A and B capture the co-presence between users 1 and 2 and between users 1 and 3 within the same area, respectively. In a planar representation of the spatiotemporal cube with the street network, it is recognised that the average cognitive distance between the users in the two cylinders varies (Figure 2b). Street A is more likely to be the place where users 1 and 2 can encounter one another, while street B is the place for users 2 and 3 to meet. Since street B is more configurationally distanced from the actual places where these two users are present compared to street A, street A will maintain a higher degree of co-presence intensity than B.

Co-presence can be measured in different ways with different spatial unit settings. One typical method is individual-based, in which the personal social network is focused and every person can be treated as a node in his/her social network. Another method is place-based. In those models, the co-presence in place is concentrated by mapping the exposure of people in certain places. These models are also similar to those mapping the spatial segregation of people. This study applies the latter model as it emphasises the role of space in connecting people and it enables a comparison between the co-presence patterns and other features of the built environment.

3.2.2 CO-PRESENCE MEASURES

3.2.2.1 IDENTIFICATION OF USER GROUPS

This study focuses on two specified social groups of people (social media users) based on their differentiation in travel (check-in) behaviours, including local users and remote users of the public space as detected by social media. The random users for location i refer to people who walk randomly between places in the neighbouring area within a fixed time interval. The so-called remote users for location i are external visitors who use incoming flows towards the neighbouring area of location i from somewhere outside. In other words, the local users are part of the internal flow, and the remote users are parts of the incoming flow. In Figure 6-2-b, user 2 is a local random user in the nearby streets, whereas users 1 and 3 are defined as remote users with a far less frequent presence. Based on these definitions of user groups according to their mobility variations, this study focus on the relative, perceived difference in terms of their travelling behaviours instead of the absolute inherent difference between people in their social classes. In reality, few people can directly judge if the persons they encounter in the street are local or non-local for a certain place. Instead, they can tell if they met someone somewhere. That is to say, people define others as locals or not according to their encounter frequency, which is directly related to mobility patterns in urban space. If someone is continuously present in a place, new visitors would feel familiar with him/her when they travel to that place at the same time. This study suggests that using the observable mobility backgrounds of people to define their place-related social groups is closer to the real mechanism that people use to define others in the built environment (e.g., Bourdieu 1987; Crane 2012). Moreover, this method, in some sense, is consistent with methods that are applied in transport geography to detect housing and job addresses, in which visitation frequency is a key factor in determining the place-identities of citizens. In addition, the identification of user groups for a co-presence analysis in this research is movement associated. The agglomeration of random travel behaviours is close to pedestrian movement illustrating the capability to retain people in space; by contrast, long trips are purposeful, reflecting attractiveness on a city-wide scale. Thus, the co-presence between local
and non-local users, in this sense, is not only an observation of physical interaction, but also a measure representing the publicness of a place from a mobility perspective, which is one of the core issues in urban design.

3.2.2.2 SPATIOTEMPORAL PRESENCE

SPATIOTEMPORAL PRESENCE INTENSITY OF THE LOCAL RANDOM USERS

The spatio-temporal presence intensity index of local random users \( \text{PRE}^\text{Random} \) measures the configurational accumulation of transitions between the venues inside the neighbouring area for a location defined by a given radius within a fixed time interval. Formally, it can be represented in the equation shown below, where presence intensity is the ratio of the metric presence density \( \text{Den}^\text{Local} \) to the cognitive distance \( \text{Dis}^\text{Local} \).

This idea originates from the spatial interaction model, but transforms its initial form to a simpler version. The metric presence density is calculated as the sum of the weights \( W_{(j,t)} \) of all the reachable check-ins at radius \( r \) within time interval \( \Delta t \).

This analysis uses the mean angular step depth to all accessible check-ins \( \text{MDep}_{(j,t)} \) under the fixed spatial and time situations as the extra cost beyond the energy expenditure reflected by radius \( r \). Apart from the traditional spatial interaction model in which a distance decay function is adopted with a calibrated parameter, this model maintains the methodological conciseness for result interpretation by using the mean angular step depth as a denominator. By assuming the trips for a user \( l \) can be represented as a set of checked-in locations in sequence:

\[
\text{Tri}_{l} = (C_{1}, C_{2}, \ldots, C_{t-1}, C_{t}, C_{t+1}, \ldots, C_{N})
\]

this analysis applies the walking distance \( \text{dist}_{(j,t)} \) between the checked-in location \( j \) and the location of public space \( i \) and the network distance between \( \text{dist}_{(i,t-1)} \) the origin \( C_{t-1} \) towards the destination \( C_{t} \) and the location \( i \) in question to extract the local random users for a specific location from the mobility patterns. The criterion for this spatial selection is constraining these two distances to a shorter degree than the given radius to identify the buffer zone for location \( i \)

\[
\text{PRE}^\text{Random} = \frac{\text{Den}^\text{Random}}{\text{Dis}^\text{Random}} = \frac{\sum_{j=t}^{N} W_{(j,t)}}{\text{MDep}_{(j,t)}} \quad \{\text{dist}_{(i,j,t)} \leq r, \text{dist}_{(i,j,t-1)} \leq r, t \in \Delta t\} \quad (1)
\]

SPATIO-TEMPORAL PRESENCE INTENSITY OF REMOTE VISITORS

The spatiotemporal presence intensity index of the local random users \( \text{PRE}^\text{Remote} \) measures the configurational accumulation of the transitions towards the neighbouring area for location \( i \) in question from the places outside within a fixed time interval. Being similar to the presence intensity of random users, this index is defined as the interplay between co-presence density \( \text{Den}^\text{Remote} \) and distance \( \text{Dis}^\text{Remote} \) for the remote visitors.

The mathematical expression is shown below, in which, \( \text{dist}_{(i,j,t)} \) represents the distance between location \( i \) and the checked-in destination \( C_{t} \) within the same given time interval \( \Delta t \), while \( \text{dist}_{(i,j,t-1)} \) and \( \text{dist}_{(i,j,t+1)} \) denotes the distances from location \( i \) to the previous and the subsequent checked-in location \( C_{t-1} \) and \( C_{t+1} \), respectively. Though controlling these distance metrics (having \( C_{t} \) located in a local area for the targeted location, but its predecessor and successor outside that buffer), remote visitors can be successfully identified.

\[
\text{PRE}^\text{Remote} = \frac{\text{Den}^\text{Remote}}{\text{Dis}^\text{Remote}} = \frac{\sum_{j=t}^{N} W_{(j,t)}}{\text{MDep}_{(j,t)}} \quad \{\text{dist}_{(i,j,t)} \leq r, \text{dist}_{(i,j,t-1)} \geq r, \text{dist}_{(i,j,t+1)} \geq r, t \in \Delta t\} \quad (2)
\]
3.2.2.3 SPATIO-TEMPORAL PRESENCE BALANCE

The spatiotemporal balance index measures the equilibrium between the presence densities of predefined social groups of people. Normalised information entropy is applied to quantify the degree of balance. Assuming there are K (k=1,2,3,...,K) groups of people in question, this research calculates the temporal presence probability \( P_{(i,k,\Delta t)} \) for each group by subdividing its presence density \( \text{Den}_{(i,k,\Delta t)}^k \) by the total presence density of all groups. In this study, only two complementary social groups of people are accounted for (k1= random, k2= remote).

\[
BAL_{(i,r,\Delta t)} = -\frac{\sum_{k=1}^{K} P_{(i,k,\Delta t)}^k \ln(P_{(i,k,\Delta t)}^k)}{\ln(K)}, \{\text{dist}_{(i,j,t)} \leq r, t \in \Delta t\} \quad (3)
\]

\[
P_{(i,k,\Delta t)}^k = \frac{\text{Den}_{(i,k,\Delta t)}^k}{\sum_{k=1}^{K} \text{Den}_{(i,k,\Delta t)}^k} \quad (4)
\]

3.2.2.4 SPATIOTEMPORAL CO-PRESENCE INTENSITY

The spatiotemporal co-presence intensity index measures the extent to which various complementary groups of people cluster at the local area around location i at radius r within a given time interval. The formal expression is shown in equation 5 which is similar to the form of calculating the presence intensity by combining the presence density and diversity. But this measure takes into account the balance factor as a weighting parameter for presence density. In so doing, this research conceptualises the spatiotemporal face-to-face co-presence as the interplay among density, distance and their balance with the people, space and time constraints.

\[
COP_{(i,r,\Delta t)} = \frac{\text{Den}_{(i,r,\Delta t)} \cdot BAL_{(i,r,\Delta t)}}{\text{dist}_{(i,j,t)}}, \{\text{dist}_{(i,j,t)} \leq r, t \in \Delta t\} \quad (5)
\]

3.2.2.5 SETTINGS

The proposed framework and detailed measures are extendable to the applications of relevant questions at various spatial scales. In this study, street segments are selected as the basic units for analysis since they are real spaces where face-to-face co-presence occurs with the metric and geometrical distance metrics, and it is vector-based without the modifiable areal unit problem that would impact the robustness of the analysis. The other two basic parameters in the introduced measures are the radius r for defining the local area of the segment i and the time interval \( \Delta t \) for identifying the time resolution. This study utilises a 750 m walking distance as the radius that defines the buffer zone for segment i based on an assumption that the average walking speed is approximately 5 km/h and the average waking time is 9 min (Bohannon 1997; Long and Thill 2015). Additionally, 1 hour is used as the interval because it was found that 1 hour is an optimised time scale for the proposed analysis, as making the time scale smaller would risk compromising the reliability of data since the average sample size would be accordingly smaller. Face-to-face encounters normally occurs within a short time, maybe a few seconds or a few minutes. Nevertheless, such a fine-scale co-presence pattern may generate bias with a large amount of variability but less regularity thereby constraining the production of reasonable patterns. Thus, it is argued that selecting 1 hour as the time interval is a rational choice for producing robust results with a good balance between temporal singularity and regularity.

3.3 INDEXING THE CENTRALITIES OF SPATIAL CONFIGURATION

The spatial configuration contains two interdependent sub-systems: the spatial network and land-use patterns. By converting these two systems into graph-based representations, this study computes the graph centralities of these two systems separately, including the space syntax centrality and urban function connectivity measures. The former measures the
shallowness between space and space, while the latter covers critical aspects of relatedness between urban functions along the spatial grids.

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Space syntax centrality measures</strong></td>
<td></td>
</tr>
<tr>
<td>Integration</td>
<td>INT %Radius%</td>
</tr>
<tr>
<td>Choice</td>
<td>CHO %Radius%</td>
</tr>
<tr>
<td><strong>Urban function centrality measures</strong></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>DEN %Radius%</td>
</tr>
<tr>
<td>Diversity</td>
<td>DIV %Radius%</td>
</tr>
<tr>
<td>Distance</td>
<td>DIS %Radius%</td>
</tr>
</tbody>
</table>

Table 1 - Centrality measures of spatial configuration

3.4 REGRESSION ANALYSIS

To explore the influence of the configurational centrality measures on the spatiotemporal co-presence intensity and the related community structure, a multivariate linear regression model is applied. This study employs the stepwise technology in the regression models to select the most important factors determining the observed variation of the dependent variables by filtering out the factors with less contribution to the model goodness-of-fit. This method can efficiently control the risk of over-fitting and produce an essential variable structure. Before the stepwise variable filter method is applied, the variables maintaining the higher risk of multicollinearity are detected and removed. The principle is defined by setting the threshold of the variance inflation factor (VIF) for each variable. In this study, the variables with VIF values bigger than 10 are removed from the models.

4 THE MATERIALS

4.1 STUDY AREA

Central Shanghai is selected as the case for the empirical investigation in this research. Shanghai is one of the mega-cities in current urban China (Figure 3). Per the national economic capital growth, it has been growing dramatically since the 1860s. The urbanisation process in Shanghai is Chinese modernisation in miniature. The spatial expansion and the shift of the spatio-social structures provide an ideal case to examine the interactive relationship between the spatial form and temporal social processes. Meanwhile, as one of the most developed cities in China, Shanghai maintains the largest group of social media users due to its large population base and a high rate of social media penetration, which enables the presupposition of using the social media dataset to precast people’s movements within the city.
4.2 STREET NETWORK AND CHECKED-IN POIS

The street network of Shanghai was gathered from an online navigation service provider with detailed spatial information. The street network data in Central Shanghai were spatially clipped from the raw data and transformed into a segmental map by maintaining the spatial axiality of the streets, which represents the topo-geometrical nature of the spatial grid. The processed segmental map consists of 92,920 street segments.

POI data and the associated check-in information were obtained through an application programming interface (API) of a Chinese social media service provider – Sina microblog, which is equivalent to Twitter in western countries. This dataset consists of a type of place-based data recording the total accumulated check-ins and the number of users who checked-in. Other features include the typology of the POIs and their coordinates. There are 191,035 checked-in POIs within the study area, which are categorised into eleven main types of complementary non-residential land-uses, including retail, catering, hotel, office, recreation, public service, park, education, hospital, culture and transport. The criteria used to classify the land-uses is the intergroup similarity of the check-in behaviours. This process can reduce the dimensions of land-use types by maintaining the most inherent information regarding land-use typology. In this study, 256 types of land-uses in the social media location-based service system are summarised according to the defined active land-uses.

4.3 SPATIOTEMPORAL TRIPS IN SOCIAL MEDIA CHECK-IN DATA

The intra-city trajectory patterns of social media users are extracted from individual check-in records collected on workdays for a quarter-long period from March to May 2016. The raw dataset includes 2,868,972 records of 73,427 users across 48,234 venues within the boundary of the study area. Even though social media check-in records are a type of fine-scale location data regarding the spatiotemporal presence of smart-phone users, they can hardly be directly used to estimate the real mobility distributions due to the existence of fake check-in records. Following the method proposed in the study conducted by Wu et al. (2014), this study applies a rule-based method to produce a spatiotemporal dataset regarding the trips of individual social media users on a typical workday. The steps to extract the spatiotemporal trips include: 1) removing invalid check-in records in which the actual locations of the smartphone users do not match the locations of the venues to which they want to check in; 2) removing the users who have only checked in once; 3) producing spatiotemporal trips of a person based on his/her consecutive check-ins; 4) eliminating anomalous trips with unexpected travel speed or duration (the thresholds of speed and duration are 400 km/hour and 12 hours, respectively); 5) merging extracted trips into a typical workday (the initial check-in trajectories for a user on different days are segmented as substantive groups with unique IDs); and 6) eradicating the trips that do not
move towards the locations in the study area. The data that were ultimately obtained include 584,746 trips towards destinations in Central Shanghai. The aggregated results between the census units are shown in Figure 4, in which the directional polycentric structure is illustrated.

Figure 4 - The aggregated trips between census units in Cantal Shanghai

4.4 GATE COUNTS
Gate count data were collected on several workdays in November 2016, covering the main streets in 10 census areas that were randomly selected (Figure 5). In each gate for an individual street segment, the aggregated flows in three one-hour-long intervals are counted. These are the time periods from 9:00 to 10:00, 14:00 to 15:00, and 21:00 to 22:00. These data are prepared to validate the reliability of social media check-in data in describing urban movement and to prove the effectiveness of the proposed method to quantify the co-presence intensity.

Figure 5 - Gate count data in the randomly selected census areas
5 EMPIRICAL RESULTS

5.1 PRELIMINARY VALIDATION

Before the introduction of the empirical results, one primary task is to validate the reliability of the extracted trajectories and the computed patterns of the spatiotemporal co-presence between the random users and remote users. This aim is achieved in the present study by conducting two comparisons. The first comparison concerns the scaling nature of the mobility data in social media check-in records, while the second concerns the goodness of the correlation between the calculated co-presence intensity and the surveyed gate counts. In this regard, this study verifies the effectiveness and applicability of the proposed methods and the framework.

5.1.1 SCALING NATURE

It has been widely discussed that scaling phenomena are common in mobility patterns. The scaling property of a distribution can be specified and modelled in several ways. For instance, it can be fitted by a pow-law function \( f(x) \sim x^{-\beta} \) or an exponential function \( f(x) \sim e^{-ax^2} \).

In this study, both models are tested. It is found that individual movement records in social media check-in data are more likely to be governed by an exponential law. As shown in Figure 6-6, the pattern of the trip length has a good fit (\( R^2 = 0.952 \)) with an exponent of \( \alpha = 0.121 \), and the duration distribution is well modelled with a larger exponent \( \alpha = 0.144 \) (\( R^2 = 0.977 \)). These results are in accordance with the findings in previous studies (e.g., Liang et al. 2012; Liu et al. 2014; Wu et al. 2015). This is evidence that the extracted trips in this study maintain the inherent scaling structures of human movement distribution, indicating the feasibility of using the social media check-in records in relevant studies.

![Figure 6 - Distributions of trip length and duration ((a) the exponent fit of the trip length pattern; (b) the exponent fit of the trip duration pattern)](image)

5.1.2 CORRELATION WITH GATE COURTS

Co-presence patterns are rooted in urban mobility distributions. Despite the fact that co-presence patterns are more complex than the flow volume, the urban flow volume is the primary factor determining the underlying probability of people’s physical interactions. Spatially varying co-presence patterns should be reasonable estimations of pedestrian flows. Consequently, the accuracy of the produced results is evaluated preliminarily by the examination of their correlation with the survey data. Figure 6-7 illustrates the scatter plots in which the gate count is understood to be a function of the co-presence variable over three time periods. The results indicate that spatiotemporal co-presence patterns generated by the proposed method are
highly correlated with the survey data and this trend is sTable 6-across time, with R-square values larger than 80%. These findings show that the dynamic co-presence patterns can not only capture the spatial discrepancy of urban flows but also portray their temporal disparity.

Figure 7 - Scatter plots of gate counts against co-presence index and (Correlation (9:00-10:00) - R2:0.8522, (14:00-15:00)-b – R2: 0.8207, (21:00-22:00)-c – R2: 0.8068)

5.2 SPATIOTEMPORAL CO-PRESENCE PATTERNS

5.2.1 DESCRIPTIVE STATISTICS

5.2.1.1 FREQUENCY DISTRIBUTION OF TRIPS

Figure 8 shows the frequency distributions of all trips extracted from individual social media check-in records. This pattern demonstrates that the check-in behaviours of social media users tend to be more frequent in the evening. There are two peaks that can be clearly observed in the distribution: one is the morning rush-hour at approximately 8 am to 9 am, and the other is dinner time, at approximately 6 pm, which is similar to what has been found in other studies (e.g., Wu et al. 2014). This distribution is different from the patterns observed in transport hubs, in which the morning and evening frequency peaks are typically equal. The main reason for this dissimilarity is that social media behaviours will be more frequent at non-working times when users are engaging in daily leisure activities, such as catering, recreation, etc. Although the trip datasets extracted from various data resources might vary in terms of the frequency distributions, their trends are comparable, indicating the representativeness of social media data regarding human movement.
5.2.1.2 TEMPORAL PATTERNS OF PRESENCE/CO-PRESENCE

Figure 9 describes the temporal changes of the average presence and co-presence measures. In terms of co-presence density (Figure 9a), the average degree of the clustering of random users in streets is higher than that of the agglomeration of remote users during most time periods with the expectation that the latter is slightly stronger than the former from 12 am to 2 pm. The temporal shift of the balance degree is captured in Figure 9b, in which the interaction between the presence of random and remote users is lowest at 3 o’clock in the morning and moves to over 0.4 after 8 am. The lower values observed before 8 am indicate the spatial differentiation between the local and non-local people flows because many trips occurring during this period are towards residential communities where few people will be active at typical sleeping times. The balance index then decreases to 0.45 at 11 am and increases back to 0.5 after 2 pm. This may result from the reallocation of destinations during lunch time. Similar to the trend observed in the change of the balance index across time, the value of the cognitive distance for the presence of both remote and random users reaches the lowest point and moves to the peak, but a short time collapse is also seen around lunch-time (Figure 9c). This trend demonstrates that the presence of people is more geometrically concentrated in some places but is more dispersed from a city-wide perspective during the periods when the presence density and balance degree are temporally lower.
It can also be noticed that the average cognitive distance for all users is always higher than the mean angular distance between people in the same group. Furthermore, the mean angular distance for local users encountering one another in the street is higher than that for remote users, which suggests that destinations for non-local users are more configurationally closed, whereas the journey’s ends for local random walkers are geometrically scattered but are metrically concentrated. The maps of presence/co-presence intensity indices are illustrated in Figure 9d. The gap between the presence patterns of local and non-local users in terms of presence density is shortened when the cognitive distance is taken into account. The co-presence intensity index exhibits a relatively smooth change and is located in the interval between the two presence intensities of individual groups. In short, the significant fluctuation of the presence and co-presence intensity patterns reveals the temporal complexity of co-presence patterns which is difficult to capture in aggregated descriptions of urban flows.

5.2.2 SPATIOTEMPORAL CO-PRESENCE MAPS

The spatiotemporal change of the co-presence intensity is mapped in Figure 10 with the same symbolising method. The overall urban polycentric structure can be discovered across time based on visual judgement, although the shape of the co-presence cores changes dynamically. This suggests that the co-presence pattern has its roots in the urban structure. In the early morning, the co-presence pattern becomes compact around the city centres, particularly from 4 am to 5 am. When the commuting time approaches, the co-presence intensity turns to be more spatially homogeneous since people are travelling to workplaces that are distributed in a more scattered manner. The global city centre regains its dominance after 9 am in the
morning, and this trend remains significant during the rest period. Notably, some locations are also highlighted for an all-day period. Hongqiao Airport, for instance, maintains a high degree of physical co-presence values at all times. This is evidence that modern mix-used complexes, such as transport hubs, shopping malls, etc., and the streets connected to them are emerging places for human interaction.

5.3 THE CONFIGURATIONAL LOGIC OF THE SPATIOTEMPORAL CO-PRESENCE

This study applies a stepwise multivariate regression method to explore the impact of every centrality measure on the variation of co-presence intensity at every hour of a workday by controlling the influences of other factors. The regression results are shown in Table 2. It is standard for all model specifications that accessible function densities at the microscale and mesoscale are the main determinants significantly correlated with co-presence intensity. The global density, however, exerts negative effects on it. This suggests that land-use clustering at smaller scales provides the basic landscape for physical interaction between local and non-local citizens. Another general trend documented is that pedestrian land-use diversity is a suppressed factor but the global diversity is an augmented factor, which yields a tendency where the local mixture of urban functions is not simultaneously preferred by the two defined groups of people if the density effects are fixed. Likewise, the places where people are more likely to be co-present are inferred by a longer angular distance at the local scale, but less cognitive efforts at the global scale. These results imply that co-presence occurs at the locations that are metrically proximal to but configurationally distanced from the areas where the clustering of urban functions manifests at the middle scale. In other words, the stages for physical co-presence may not always be high streets; rather, they are more likely to be the places connected to central streets as the interfaces between centre and centre.

Angular integration and choice variables at low levels are also positively associated with the change of co-presence intensity across time, but their statistical significance varies. Angular integration variables are more significant in specific models before 12 am. In the afternoon, angular choice variables are more significant than the integration elements. What results this might be the fact that the co-presence that occurs in the morning is related to the to-movements driven by the closeness between spaces. This demonstrates that developing areas – the places lacking sufficient local amenities but being fulfilled with adequate housing and employment opportunities – are captured by integration variables at local scales, play more important roles in the spatial co-presence patterns in the morning work hours and late night, when people are committing across the city to their workplaces and homes. By contrast, non-working and non-residential activities are more dominant during other periods within a typical workday; thereby, the impact of angular integration becomes less statistically significant. In a nutshell, spatial centrality measures are significant factors for predicting temporal co-presence patterns using functional centrality indices, and the dynamic change of their significance reveals the composition of various types of urban movements across time.
Figure 10 - Spatiotemporal co-presence maps in Central Shanghai
ENCOUNTER AND ITS CONFIGURATIONAL LOGIC:
Understanding spatiotemporal co-presence with road network and social media check-in data

| DEN_R500 | 0.575 | 0.516 | 0.574 | 0.572 | 0.599 | 0.606 | 0.614 | 0.367 | 0.645 | 0.577 | 0.636 | 0.684 |
| DEN_R2500 | 0.429 | 0.465 | 0.417 | 0.350 | 0.414 | 0.434 | 0.228 | 0.157 | 0.326 | 0.360 | 0.390 | 0.366 |
| DEN_R10000 | -0.263 | -0.282 | -3.353 | -0.31 | -0.302 | -0.231 | -0.146 | -0.190 | -0.112 | -0.113 | -0.357 |
| DIS_R500 | -0.132 | -0.124 | -0.153 | -0.113 | -0.12 | -0.112 | -0.079 | -0.084 | -0.082 | -0.099 | -0.094 |
| DIS_R2000 | - | - | - | - | - | - | - | - | - | - |
| DIS_R10000 | 0.037 | 0.037 | 0.037 | 0.043 | 0.067 | 0.096 | 0.057 | 0.033 | 0.039 |
| DIV_R500 | -0.078 | -0.121 | -0.057 | -0.032 | - | - | - | - | - |
| DIV_R2500 | - | - | - | - | - | - | - | - | - |
| DIV_R10000 | 0.025 | 0.028 | 0.037 | 0.037 | 0.043 | 0.067 | 0.096 | 0.057 | 0.033 |
| DIV_R10000 | -0.065 | -0.066 | -0.080 | -0.055 | -0.069 | -0.043 | -0.047 | -0.044 | -0.041 |
| DIS_R500 | 0.064 | 0.056 | 0.037 | 0.038 | 0.063 | 0.073 | 0.062 | 0.069 | 0.096 |
| DIS_R2000 | - | - | - | - | - | - | - | - | - |
| DIS_R10000 | -0.065 | -0.066 | -0.080 | -0.055 | -0.069 | -0.043 | -0.047 | -0.044 | -0.041 |
| INT_500 | 0.076 | 0.053 | 0.047 | 0.082 | 0.052 | 0.067 | 0.078 | 0.107 |
| INT_1500 | 0.251 | 0.180 | 0.175 | 0.170 | 0.163 | 0.096 | 0.103 |
| INT_5000 | -0.026 | -0.029 | -0.047 | -0.068 | -0.064 |
| CHO_500 | -0.021 | 0.091 | 0.038 | 0.045 |
| CHO_10000 | 0.029 | 0.025 |

Table 2 - Centrality performance against encounter intensity (Only significant variables are shown)

denotes to the change of the correlation coefficient in the model with only urban function connectivity measures to the model with both urban function connectivity and space syntax centralities, DEN: accessible function density; DIV: accessible function diversity; DIS: cognitive distance to the reachable land-uses; INT: angular integration; CHO: angular choice

Performance

| Adj. R² | 0.777 | 0.743 | 0.714 | 0.664 | 0.748 | 0.734 | 0.575 | 0.701 | 0.671 | 0.733 | 0.787 |
| Adj. R²(SSX) | 0.474 | 0.462 | 0.430 | 0.405 | 0.442 | 0.399 | 0.309 | 0.233 | 0.378 | 0.368 | 0.394 | 0.425 |
| Adj. R²(UFC) | 0.717 | 0.669 | 0.642 | 0.607 | 0.703 | 0.684 | 0.547 | 0.328 | 0.667 | 0.634 | 0.688 | 0.751 |
| Enhancement | 7.723% | 9.960% | 10.084% | 8.584% | 6.016% | 6.812% | 4.897% | 6.017% | 4.897% | 5.514% | 4.841% | 4.574% |
ENCOUNTER AND ITS CONFIGURATIONAL LOGIC:
Understanding spatiotemporal co-presence with road network and social media check-in data

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**Urban function connectivity measures**
- DEN: accessible function density
- DIV: accessible function diversity
- DIS: cognitive distance to the reachable land-uses
- INT: angular integration
- CHO: angular

**Space syntax metrics**
- Performance denotes to the change of the correlation coefficient in the model with only urban function connectivity measures to the model with both urban function connectivity and space syntax centralities, DEN: accessible function density; DIV: accessible function diversity; DIS: cognitive distance to the reachable land-uses; INT: angular integration; CHO: angular

**Table 2 - Centrality performance against encounter intensity (Only significant variables are shown)**
When the goodness-of-fit for every model is scrutinised, co-presence patterns in streets are proven to be properly captured by the centralities of the spatio-functional context where they are embedded. For most of a typical workday, the models with both families of configurational centralities maintain correlation coefficients greater than 0.65. However, this trend is interrupted during the period around the morning peak from 6 am to 8 am. This result implies that the co-presence patterns may be simultaneously driven by other variables that are currently absent from the present models in a more complex sense. For models with spatial and functional centrality measures, their predictability is higher than the other two types of models with either spatial or function centrality indices, suggesting the theoretical proposition that spatio-functional interaction is the essential determinant of spatiotemporal encounter patterns. In addition, models with urban function connectivity measures perform better than those with space syntax centrality metrics in terms of the size of the correlation coefficients. Nevertheless, this does not mean that the impact of the spatial network can be substituted by the influences exerted by the land-use system. Instead, these findings suggest a complimentary relationship between urban form and functions for an in-depth understanding of people’s interactions in the streets. These results further exhibit that the physical co-presence that happens in an urban reality is far more complex than was expected and hypothesised in the theory of space syntax. Additionally, the spatial centrality and land-use patterns are more important in the formulation of the landscape for people to communicate and to make a space socially public. More importantly, in comparison to the roles that the spatial grid plays, the effects of the geometrical properties of land-use patterns on the spatiotemporal encounter are more direct and powerful.

6. DISCUSSION AND CONCLUSION

This research examines the spatial logics of the spatiotemporal co-presence between the local and non-local people in Central Shanghai. Two main tasks are expected to be achieved. The first one is to quantify the spatiotemporal patterns based on the individual’s check-in records and street network. The second one is to investigate the role that the urban design plays in the sensed spatiotemporal co-presence intensity. The main scope of this study is to empirically explore the extent to which the spatial design influences the physical face-to-face interaction between different groups of people, the social media users more precisely, in contemporary digitalised society.

This study delivers a PST model in which the social capital for people to interact includes three principal dimensions including the social difference between people, the spatial distance (the metric and geometrical distance), and the time cost of people’s presence. It is proposed that people can be profiled by their mobility patterns which can further depict the citizens’ place identity from place to place and from time to time. Within a given time, interval, social media users who visit a local area for a location frequently are defined as the ‘local random users’ for that location, while the users who have a short time visit towards the local area for a location and travel back to somewhere outside the local area are identified as the ‘remote users’. From an aggregated scope, the local random users and the remote users are the parts of the internal flow and the incoming flow for a location in question, respectively. Given these definitions, this study anchored its specific focus on the physical encounter between the local random users and the remote users by considering comprehensively the required energy expenditure and cognitive cost. By giving a time radius and a distance radius, the delivered co-presence intensity addresses the interplay among the co-presence density, balance and mean cognitive distance in every street. Portraying spatiotemporal patterns is not only related to the perceived publicness of space but also helpful for producing the deeper knowledge on how the offline built environment is used by the online population in the current digitised world.
Individual’s trajectory pattern is extracted from their consecutive check-in records and then used to produce the spatiotemporal co-presence intensity in streets with the street network dataset. The reliability of the mined data and the effectiveness of the proposed method are proven by the observation that the processed spatiotemporal trips follow exponential laws in terms of the trip length and duration and a good correlation between the outputs and the small sized survey data. The co-presence patterns across time reveal their temporal complexity. Not only the city centres but also the planned centres and the large-scale social complexes, such as transport hubs, shopping malls, etc. are the crucial spaces for people to encounter. Regression results suggest that physical co-presence between the random and remote users are not always in high streets as expected, but their nearby streets where the pedestrian land-use mixture is less and the angular distance to the land-use is longer. The impacts of the angular integration in the regression models for describing the deviation of co-presence patterns are more significant in the morning when developing areas are more likely to be the destinations in the commuting time. It is validated that the urban function connectivity measures maintain higher standards of predictability than the space syntax centralities, though the model performance can be further enhanced if both types of configurational centrality variables are used. It is also noteworthy that the goodness-of-fit in the integrated model is significantly lower in the morning peak hour.

The potential contribution of this work relying on several aspects. Firstly, it is proven that social media dataset can be adopted to understand human’s mobility and presence with a large coverage and a fine spatial resolution. Secondly, it proposes a street-based framework to quantify the spatiotemporal co-presence between defined groups of people. This framework is flexible and can be extended and used to measure other co-presence phenomena. Thirdly, this work suggests that it is the spatio-functional interaction through streets that influences the spatiotemporal variation of the encounter between people, which could be a reference for the further studies on the relevant directions. Fourthly, it is recognised that land-use patterns are theoretically and methodologically necessary for understanding the social processes in contemporary society where people’s travelling decision making is biased by the online location services. Lastly, the introduced measure of co-presence intensity in this study could be considered as a spatiotemporal centrality index across places. It extends the current space syntax integration purely focusing on spatial network, to a more comprehensive centrality with land-use, spatial network, temporal and individual components, the four domains in accessibility measurements (Geurs and Wee 2004).

Further work can be conducted in, but not limited to, the following aspects. The time interval for computing the co-presence intensity in this study is set for 1 hour in order to avoid the bias caused by the data’s scarceness. In the next step, the time interval can be further divided with a better data support to produce the results with more temporal singularity. Moreover, the information of the individual check-in trajectories can be enriched by combining it with other big data resources, such as the cell phone datasets, etc. Besides, more empirical studies should be conducted in other cases to validate the generality of the conclusions in this study.
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TRIUMPH OF PEDESTRIAN:
Empirical study on the morphology of shops in Beijing’s central city area in 2005-2015

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ABSTRACT
In the last decade on-line shopping had great impact on Chinese people’s every day life. How this transformation may influence the spatial distribution or types of shops in the real urban space is a major question. By comparing the morphology of shops in 2005 with 2015 based on detail field work survey in 94 urban blocks inside the 2nd ring road of Beijing, the data suggest that in the last decade the total number of shops on the street increased rather than decreased. At neighbourhood scale, this paper focuses on three case areas: Dongsi, Xisi, and Lama temple to study the changes of different types and the detail distribution of these shops. The result shows that with the development of information technologies the emerging shops are mostly service-based economies such as restaurants and pubs, or retails but more oriented to local people and tourists. Furthermore, the city-scale shops on the super grids retains its vitality. They also tend to penetrate into the local streets inside the urban block. On the other hand, the morphology of local shops is affected by the visibility from super grid and the syntactical connection of these streets in its local surroundings.

KEYWORDS
Morphology of shops, pedestrian, information technology, Space Syntax.

1. INTRODUCTION
Shopping behaviour in China has been changed profoundly based the rapid development of information technologies. Benefiting from relatively cheap delivery cost and tax-free policy, online shopping has become an indispensable part in Chinese people’s daily life. However, it is also accused to play a negative role on the shops in real urban space.

Even before the spread of internet and smart phones, there were debates among scholars back to 1990s on the impact of informational technologies. At the beginning some scholars believed that they will make the geological space irrelevant (Graham, 1998). However, later empirical studies in the beginning of 20th century suggests that the informational technology may have a two-fold impact: on the one hand it may help the decentralization of certain economic sectors such as manufacture into suburbs or smaller towns. On the other hand, it also requires higher
level of concentration of other type of sectors such as management and advanced services. Saskia Sassen's research on global cities is one example (Sassen, 2002).

In China, recent researches also focus on this transformation (Liu & Zhen, 2004). Prof. LuZi's research on the online group-buying behaviour in Shijiazhuang (provincial capital of Hebei) suggests that the online business rely on even higher degree of spatial concentrations in real urban space (Lu et al, 2013). However, in his research the centre of concentration is defined by distribution of shops based on the metrical distance rather than an urban structure which could explain the underlying spatial logic between movement and urban economies.

For space syntax researches, the influence of urban structure on the spatial distribution of shopping functions is a well-studied issue for decades (Hillier et al, 1996, 1999, Siksa, 1997, Scoppa & Peponis, 2015). Recent development of information technologies has brought vast open data resources. Using Baidu Point Of Interest (POI) data, Yang Tao has studied the spatial distribution of various types of urban functions in Beijing's metropolitan area. His research not only illustrates different types of functions depends on different scales of accessibility, but also discovered more detail properties such as cost or style of restaurants have different spatial pattern (Yang, 2015). Other than providing vast yet detailed location data of shops, the new information technology could also render the use of these shops visible. Using number of reviews and check-in data, Yao Shen's study in Tianjin also demonstrate the value of space syntax model in analysing the spatial distribution of different types of shops (Shen and Karimi, 2016).

For morphological research on the changes of shops, because these new data sets is only available from 2010s, and the resolution and accuracy of early data set is poor. It is very hard to compare data from different periods. There is a lack of morphological study based on detailed and consistent data of shops for one city.

In 2005-2008, the author did a detailed survey on the distribution of shops on each the street inside the third ring of Beijing. From 2013 to 2015, we did another survey in the same area using street view map and fieldwork. Considering 2005 to 2015 is a period that on-line shopping has a dramatic booming development, this comparative study should be able to show clearly the impact of new information technologies. Meanwhile, although the road network at large metropolitan scale and the metro system has been developed in last decade, Beijing's central area road network has not changed too much. Therefore choosing the central area of Beijing as a case could study the morphology of shops in a relatively stable spatial condition.

The main research question of this paper is: what is the morphological logic for different types of shops in the central area of Beijing in the last decade? To answer this question, this research is divided into two parts based on the scales: at city scale, a statistical analysis will be presented to illustrate the changing number of shops on the super grid and inside each super blocks. The preliminary result shows that the total number of shops inside the 2nd ring road are increasing instead of decreasing. Furthermore, the majority of emerging shops are located inside the super block rather than on the super girds. At local scale, three case areas are selected for more detailed analysis, based on Baidu street view map, the new shops are divided into 30 types according to the commodities or service they provide. For each case the distribution of shops is analysed based on an integrated index of accessibility and visibility from super grid (space for vehicle) and the local street pattern (space for pedestrian).

2. DATA AND MODEL

This research focuses on the urban area inside Beijing's 2nd ring road. The main data set is the location and number of shops in 2005-2008 and 2013-2015. The data collected between 2005 and 2008 is based on fieldwork mapping of all shops on each streets inside the 3rd ring road. The area covered 160 square kilometres. These shops were classified into three types initially according to the types of commodities or services. Metropolitan scale shops are those wholesale centres of specific commodities, shopping malls, hobby shops, etc. Local scale shops are those local food markets, street venders, clubs (Qipaishi), grocery stores, etc. All other
shops are classified as middle scale shops. For the clarity and convenience of this research, the metropolitan and middle scale shops are all re-classified as city-scale shops.

Between 2013 and 2015, our team did another round of survey in the same area using the Baidu street view map and fieldwork. With the help of street view, the detail types of shops could be recorded to compare with the old data.

Figure 1 shows the combined data based on fieldwork and the street view map. Constraint by the accessibility of car used by Baidu Company to take photos, there are always some streets which could not be reached. This paper will demonstrate that the changes inside those ‘invisible’ streets are also interesting research subject because it could reveal the spatial expansion of shops in last decades.

On this stage the main research area is within the 2nd ring road. To give enough buffer zone, the spatial model covers all streets extracted from Baidu OSM (highest resolution which includes minor streets inside the neighbourhoods) within 5th ring. To weight the regional scale movement the model also includes satellite towns such as Changping, Shunyi, Mentougou, etc.
These towns are connected with Beijing city by simplified highways (see figure 2). The model of 2015 and 2005 are constructed in the same range and resolutions.

3. CITY-SCALE ANALYSIS

Based on the author’s previous research on the spatial pattern of local centres, the urban area inside the 2nd ring road could be divided into 94 super blocks based on multiple factors ranging from the width of the road, the number of bus lines and syntactical values [11].

Figure 3 shows changing number of shops on the super grid and inside the super block in between 2005 and 2015. Comparing the data between these two years, on the super grid there are 2558 new shops opened and 1257 shops closed. Inside the super block there are 5143 shops opened and 2267 shops closed. Both number indicates that despite of the booming on-line economy in the inner city of Beijing there is a clear growth of shops in real urban space in the last decade. This statistical result also indicates that the changing number of shops inside the super block plays a more important role than those on the super grid. It accounts for 68.86% of total increase. Even considering the total street length of super grid itself (18.706km) and the local streets inside super block (38.175km). The growth of shops inside the super block still outnumber that on the super grid.

When focusing on the changing number of shops inside the super block, there are only 13 out 94 super blocks have less shops in 2013-2015 comparing with 10 years ago. Among these 13 blocks, Qianmen (CB139), National Opera Center (CB128), Tiantannanli (CB181) have less shops because of the urban redevelopment process. After excluding the impact of redevelopment, there are only 10.6% of the super blocks has decreasing shops in the last decade. On the other hands, there are also some areas that has substantially higher number of new shops opened in the last decade. The Huashi area (CB141-144) and Xizhaosi area (CB169) are such examples because of the housing redevelopment projects. Figure 4 shows the dramatic changes in the last ten years. This area proved to have great resilience under this impact and the shops and street life quickly recovered.
Is there a general spatial pattern for this change? In figure 5 the left image shows the metrical distance from super grid. The blue color indicates longer distance. From the statistics most new shops and closed shops are located 0-300 away from the super grid. However, because average size of super grid is 500-600 meters by 500-600 meters, so this result does not show a clear logic. The image on the right shows the topological distance from the super grid. One topological step means 90 degree of angular change between two streets. Considering the fact that small angular changes are hard to be sensed by moving people, a threshold is set on 13.5 degree which is 0.15 steps. According to the results, shops located on the super grid directly (<0.15 step from the super grid) accounts for more than one third of the new shops and closed shops. The street connected to the super grid (0.15-1.15 step) accounts for almost 50% of the changes. This result suggests that although the super grid support higher flow volume, the growth pattern of shops inside the super block does not affected by distance from the super grid but rather by angular turns. It is not suffered from distance decay but rather topological decay.
To sum up, this preliminary analysis reveals a general pattern of changes happened in the last decade: most changing shops are located inside the super block on those street directly visible from the super grid (about 1 step). Although on this stage it is too early to state that the on-line shopping can have positive influence on the shops in real space, it is clear that in the central area of Beijing the shops are still expanding in the last decade when the virtual economy is booming.

Is there any difference between city-scale shops and local-scale shops inside the super block? Figure 6 shows the numbers of city-scale and local-scale shops emerged in the last decade within each of these 94 super blocks. As a result, Nanluoguxiang (CB055), Lama temple (CB041), Xizhaosi(CB169) and southeast corner of Huashi(CB144) have more than 100 city-scale shops emerged. Qianmen-dashila(CB138), Xizhaosi(CB168 and CB169), southwest corner of Xuanwumen(CB136) and Xintaicang(CB057) have large number of local-scale shops emerged. There is little correlation between the increase of city-scale and local scale shops inside the super blocks (R square value 0.0684). This result indicates that the changing pattern of city and local scale shops might follows very different spatial logics. In later part of this paper we will explore this detail in three selected cases.

From the scatterplot in figure 7, three case areas are highlighted: Lama temple (CB041,CB042) is an area with booming commercial functions (City-scale shops plays a leading role); Xisi (CB071,CB072,CB073,CB089,CB090,CB091) is an relatively stable area; Dongsil(CB078, CB094) is an area suffering declining from 1990s. Xizhaosi area (CB079) is also a remarkable cases which local shops play a leading role. However, as mentioned before this area benefited a lot from the massive housing redevelopment so it is not a representative case. In the next part of the analysis these three cases will be further studied.
Before zooming into these three cases, it is necessary to look at how city scale movement network changed during these ten years. This may show if the changing number of shops of each three cases in general could be explained by the change in spatial structure.

In figure 8, the top 5% of the street segments with high NACH R50km values are presented as red thin lines, top 5% NACH R10km is presented as thick pink lines. These two values indicate the through movement potential of 50km and 10km radii respectively for vehicles. The former could be understood as the regional or metropolitan scale connection. The later could be understood as the city scale connection. The NACH R1km which illustrates the distribution of local movement within 1km radius. It is shown as grayscale lines in the background, the darker the higher value. This value could be understood as the local movement potential for pedestrians. Comparing the morphology of large scale urban movement networks, there is a clear tendency that it evolves towards a more regular orthogonal super grid pattern. In these 10 years, although there is seemingly little changes in the central city of Beijing, some minor interventions on the road network (connecting the dead-ended streets, extending the main roads, etc.) still can affect the large scale structure to some extent. As a result, the city-scale centre becomes more integrated which could possibly explain the increase number of shops for most super blocks. However, the through-movement potential for main individual main streets may decrease because a regular grid structure can provide more options. For example, the main streets in Dongsi, Xisi and Lama temple area are also decreasing in NACH R10km. But when we look at the NACH R50km, due to the extension of airport highway to the 2nd ring in southwest direction, Lama temple areashows a clear increase: 5.3% for the roads running east-west, 6.6% for the roads running south-north. Xisi area retains its commercial vitality because the north-south main road (Xisidajie) remains relatively stable (-1.3%), although the east-west main road (Wenjinjie) drops dramatically (-10.7%). Dongsi area continues to decline because it has decrease NACH values in both two directions of the main roads, -5.9% in north-south, -8.6% in east-west. Future study will be focusing on analyse more case areas, but on this stage the city (or regional/metropolitan) scale connection of super blocks could explain the changing number of shops to certain extent.

Except for the road structure, another change in movement network is the development of metro system (see figure 9). In 2005 Beijing has opened three metro lines: Line 1, Line 2, and Line 13. Metro line 5 is opened in 2007. Line 4 is opened in 2009. Line 6 is opened in 2013. For our three cases, Lama temple is on line 2. And later became an interchange station of Line 5 and 2.
Dongsi is a station on Line 5 and later became an interchange station of Line 5 and Line 6. Xisi is a station on Line 4. According to the entry/exit data of metro stations in 2014, the average number of daily passengers coming in and out of Lama temple station is 51710, Dongsi is 38383, Xisi is 22949. Clearly, Lama temple benefits most from the metro system developed in the last decade.

Figure 9 - the passenger data of Beijing Metro system in 2014. Black lines were opened before 2005. Red lines were opened after 2005. The size of circle stands for the exit/entry data of stations. The thickness of lines stands for the volume of flow between two stations

4. LOCAL-SCALE ANALYSIS

4.1 DONGSI CASE

This part of the research will compare the changing number and types of shops in three case areas. Because the data in 2005 do not have detail classification of types, this research can only include detail types for those shops emerged in 2015. Unfortunately for those shops changed its types or upgrade from local-scale to city-scale is omitted. It means this research only focuses on those changes from residential or other land uses into commercial land use or vice versa. In fact, commercial functions in city are very vibrant, in one or two years they may change from retails to restaurants. Furthermore, a street with large number of shops that are changing their types of business can be a sign of either processes, increasing commercial opportunities or declining. Therefore, changing land uses which is a slower process can represent the commercial vitality in a stable way.

Let us start with a declining case, Dongsi area. Figure 10 shows the case of Dongsi which suffered a contiguous declining since 1990s. Dongsi used to be one of the most popular shopping centre in the last century. However, due to the rapid urban development, the importance of Chaofudajie (east-west main road) as city-scale movement network were substituted by Changandajie and PingAndajie gradually. As mentioned in early part of this paper, the main roads in both directions are reduced substantially in the last decade. In fact, Dongsi is top one declining case inside the 2nd ring road after excluding the influence of redevelopment project in other areas such as Qianmen. Even though, in figure 10 one still can see some street segments in this area have new shops.

In the bar chart in figure 10, 30 types of shops are listed. For the total 155 new shops, 85 of them are retails and 70 are service based shops. The major type is fashion (dressing) store. In the last 20 years fashion is the main shopping attraction of Dongsi area although it is kept declining.
The second and third type are the restaurant and local groceries respectively. In general, the retail-based shops still account for 55% of the total number of new shops, 10% more than that of the service-based shops.

Figure 10 - the detail types of shops emerged from 2005 to 2015 in Dongsi area.

This research is focusing more on the distribution pattern of those shops rather than the statistical fact. The map on the left side of figure 11 shows changing types of shops (city and local) on this spatial context. The purple arrows and numbers stand for the location and number of new city-scale shops. The blue arrows and numbers stand for the location and number of new local-scale shops. The white number with black edge shows the decreased number of shops. The thickness of purple line stands for the value of NACH R50km. The grayscale lines stands for the value of NACH R1km. From this map, a general spatial pattern could be described as:
1. most city-scale shops tends to penetrate into the local street from the super grid. The only growth on the super grid itself located in the intermediate space of metro station. 2. the local shops also tends to emerge on where the local street meet with the super grid. Additionally, some local shops tens to emerge deep inside the super block when these streets are of high NACH R1000 value.

Figure 11 - spatial analysis on the distribution of emerging shops in Dongsi
This pattern observed could also be visualised in a scatter plot which shows the visibility and accessibility of super grid in Y-axis and local accessibility in X-axis. Local Accessibility is measured directly using NACH R1000 value. Visibility and accessibility value is an integrated measurement of the value of NACH R50km on the super grid multiply with the angular depth (plus one) from super grid. By definition this index value could be understood as measuring the permeability of the area. In this scatter plot each crossing stands for each street segments in map. The thickness of lines in crossing stands for the number of shops emerged. The colour stands for the types of shops (city or local scale). As the result shows most streets with more increased number of shops a grouped on the middle-right area. The top-right area are the super grid segments. This result mean that most of this street segments with increased number of shops are of high local accessibility and very easily visible from the super grid. Cuifujiadao is an exception in this case because the west end of Longfusidajie is controlled by gate which only allows pedestrian to pass. Therefore many people turn to Cuifujiadao as alternative exit of this area.

4.2 XISI CASE

Xisi is a relative stable case considering the total number of changing shops. However, its balance is achieved by an increase of local-shops and decrease of city-scale shops. This area is known as the wholesale centre of electronic products and jewelleries for tens of years. Figure 12 shows the changing types of shops in Xisi area. Not surprisingly, the leading sector of growth is the local market (Xiaomaibu) and restaurants. For the city-scale retails, a few jewellery stores and digital markets also opened in some local streets connect to Xisidajie (North-South Main Street). While the east-west main street, Fuchengmenneidajie shows a clear sign of declining as a result of dropping NACH values of large value as mentioned before. In general, retails in this area still account for more than 59% of total increased number of shops. Service-based shops account for less than 41%.

Figure 12 - the detail types of emerging shops from 2005 to 2015 in Xisi area.
This distribution of these emerging shops shows a very similar pattern with the case of Dongsi. In most streets shops are emerging on where the local streets meet the super grid, which could be described as a seepage pattern. Dagaibanghotong turns to be an example of concentration of local shops only, which is relative far from the super grid. In the scatter plot, because some street such as Xihuangergenbei and Fuchengmenneidajie are of very low NACH R50 values. The integrated index of visibility and accessibility from super grid are also substantially lower than normal super grid main street such as Xisidajie. As a result in the scatter plot these ‘weak’ super grid streets forms a cluster between the majorities at bottom and the ones at top. On these ‘weak’ super grid streets the new shops emerged mainly on those street segments with relative low local accessibility. It is not a preference but simply because other streets at these level have been already occupied. For most local street inside the super block. The very same pattern with Dongsi appeared again: the streets of high local accessibility and relative high integrated index can support more emerging shops in the last decade.

Figure 13 - spatial analysis on the distribution of emerging shops in Xisi

4.3 LAMA TEMPLE CASE

Lama temple is a case which underwent a booming growth of commercial functions in the last decade. The main shopping street nowadays, Wudaoyinghutong, used to have only 5 local shops in 2005 in our first fieldwork. In 2008 a lot of bars and fashion stores already appeared. Now it even become one of the most attractive shopping streets in the inner city of Beijing after the famous case of Nanluoguxiang. In figure 14, ‘restaurant’ and ‘coffee & bar’ contribute to the total increase most. Other retail functions such as souvenir and fashion shops, local groceries (shown in dark orange, red, dark blue) play secondary roles. In general, the service-based shops account for more than 59% of the total increase, while the retail-based shops account for less than 43%. Among all three cases, this is the only one that the service-based shops outnumber retail-based shops.
As an extreme case of booming shopping area, the spatial patterns of emerging shops in Lama temple is also appears 'extreme'. Benefited from a directed access to one of the metro exits of Lama temple station in the east end, and a very close distance to Andingmen station in the west end, Wudaoying streets has attracted more than 80 new shops. It even bring opportunities other local street which intersect it directly. Jianchanghutong for instance, has attracted 9 city-scale shops and 4 local-scale shops, but it does not even visible from the outside of the superblock. It is also interesting to compare the superblock on the southwest corner of Lama temple station with the one on the southeast. The latter has clear advantage of tourist attractions. The entrance of Lama temple itself located on Xilouhutong in the southeast area. However, simply because of the complex local street pattern make it difficult to be explored by non-local people, the southeast area benefit far less from the growth although in term of metrical distance they are in same condition to the metro station. So from this case, we can see a topologically shallower local street structure can be better appropriated by pedestrians comparing with the complex ones. The local street structure itself could even create an tourists attractions and compete with existing historical ones when its linkage to the whole city is improved (by both the growing metro system and an highway leading to the airport in this case).
In scatter plot, Lama temple case has no increase number of shops on supergrid. All developments are happening inside the superblock. Despite of this difference, its growth pattern on the local streets is very similar to the other two cases. The street of high local accessibility and integrated index can attract more shops. But as mentioned before, due to the large amount of people this area attract, more local streets in relative weak spatial conditions can still benefit from the flow of tourists. Jiaodaokoubegisiantiao, Jianchanghutong and Xilouhutong are such examples.

4.4 SUMMARY OF THREE CASES

As a summary of these three cases, the service-based shops account for 49% of the total number of new shops opened in the past 10 years. Because Lama temple is one of the extreme cases of growth, Xisi and Dongsi are considered to represent common situation, we could speculate that for most areas the retail-based shops still play a leading role. This result is surprising because with the rapid development of information technologies, we used to believe that service-based shops will take the lead. To certain extent this speculation is still true because when we only focus on all 30 types of shops in three cases, the leading type is the restaurant which accounts for 19.2% of the total number. The second type is the local supermarket (Xiaomaibu) which accounts for 12.3%. Then the following ones are dressing and coffee, 11.2% and 10.6% respectively. So the catering functions in general (restaurant + coffee) account for over 30%. On the other hand, for the retail-based shops, fashion and dressing store still sustains because to buy a dress or shoe still need to try. The local groceries and supermarket, food markets or shops are normally omitted by scholars, but clearly the result shows that these daily retails serving the local people contribute a lot for the growing number of shops in the last decade.

To sum up the spatial patterns in these three cases, there are at least two types of growth patterns: the first is a seepage pattern which could be found in both city- and local-scale shops. It seems most new shops emerged on where the local street meet the higher scale movement network. The second is a local-intensification pattern for local-scale shops. It seems the streets which are well-connected in the neighbourhood but not directly visible from the border of super block could support more local shops than 10 years ago. Furthermore, there is also a third, yet very simple growth pattern. In all of these three cases on the super grid there are places with more emerging shops. These places are directly located nearby the metro stations, it is very limited in 100 meters range the and mostly along the main roads.

5. CONCLUSIONS AND DISCUSSIONS

This paper starts with a 10-year empirical study on the changing number of shops in Beijing. By comparing the changing number of city and local scale shops. The preliminary result suggests that the number of shops in the city centre of Beijing is still increasing despite of the booming development of on-line shopping. Furthermore, this growth happened more on those local streets inside the superblock. The city or higher scale movement network still matter, but they matter through a way that increase the accessibility of particular area (super block) to the whole metropolitan area. The local street pattern decides the spatial pattern of those new shops.

At local scale, the results from three selected cases areas shows that the retail-based function still plays an important role, but the service-based shops may play a leading role in new attraction areas such as Lama temple. For all of the three cases, the contribution of local daily-based retails could not be neglected.

Additionally, except for a simple distance-dependent growth pattern nearby metro station, there are two spatial patterns could be found in this three cases: seepage pattern and local intensification pattern. Generally speaking, both of them could be conceptualized as a dependence on different groups of pedestrians, either coming from a large city or metropolitan area or merely local surroundings. It is eventually a question of how movement beyond local could be interfaced with the local. The development of metro system and evolving structure of super grids in the last decade are all improvement of infrastructures which aims to facilitate travelling over longer distance. Based on the empirical studies on Dutch cities, Read stated that the contemporary cities are operating on a ‘biplex’ structure between super grid and
local streets. The former could bring an evenly distributed potential but the latter can act as attractors on the ground (Read, 2005, 2009). Following this line of thinking, even the development of information technologies might be understood as a kind of ‘infrastructure’ that facilities the decision process of travelling. Instead of making the geological space irrelevant, all of these infrastructures might lead to re-discover the value of local streets. The preliminary result on 10 years changing pattern of shops in the centre city of Beijing suggests that the local street connectivity at least still matters for the urban vitality in the informational age. Is it a generic phenomenon for other cities? Will the on-going development of both real and virtual infrastructures eventually leads to the triumph of pedestrian? These are interesting questions need to be deal with in future researches.
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ABSTRACT

To analyse the city in relation to its history, through its transformations, means also to understand the society itself. That is, the city, its connections, streets, public spaces, reveal the identity of the society. This paper explores the urban evolution of the city of Curitiba, Brazil, by historical and configurational data, from the historic downtown plan from 1857, until the more consolidated city plan in 1988. These maps were selected based on the key historical urban planning facts of the city. The theoretical background of the research is based on Space Syntax Logic (Hillier and Hanson, 1984; Hillier, 1996). This paper was organized in two moments: at first, a series of historic maps of the city of Curitiba was developed; after that, the axial maps were drawn and read. The structure of the urban street grid was analysed based on the accessibility and centrality data, through the global and local integration. This paper shows the consolidation of planning decisions with the visualization of accessibility arrangements and its connections, historically formed. When Analysing this information, it was possible to recognize the emergence of structural axes North-South and East-West, which are the most known results of the urban planning in Curitiba.

KEYWORDS

Space Syntax methodology; urban plans; city of Curitiba; urban integration

1. INTRODUCTION

The objective of this study is to understand the formation of the city of Curitiba through the analysis of its lines of integration (spatial syntax), based on its historical maps from 1857 to 1988.

To understand the city linked to the historical time, through its transformations, means to understand the society itself. In fact, it is in the city, on its connections, on its streets, in its
generated spaces, that society itself is materialized. Such study of the past also serves as a measure of comparison with the present and the future. This time – materialized by the dispute of spaces, interests, economic, social, and political issues etc.; is registered in many ways in the city, one of them, at the urban level, being the historical cartography. As said by Rossi (2001), “The shape of the city is always the shape of a time of the city, and there are many times in the shape of the city” (p.57).

The understanding of the city from its growth helps to obtain an overall scenario, since according to Panerai (2006), this type of analysis when linked to maps and field survey ends up relating the strength lines of the geographical territory with large traces that organize the urban agglomeration.

Understanding the process of urban growth is important because it provides us a global apprehension of the agglomeration in a dynamic perspective. [...] In revealing the fixed points of previous transformations, the study of growth allows one to determine those logics deeply inscribed in the territory that clarify the reasons of being the current settlement. To begin the analysis of a city by the study of its growth is one of the means of apprehending it as a whole, in order to determine the direction of further detailed studies. (Panerai, 2006, p.55)1

Bearing in mind these considerations, this paper was organized in three parts. The first one, describes the methodological procedures adopted; the second one, presents the detailed analysis of the geometry of the urban trajectory in the pre-selected historical periods of Curitiba City; and finally, the third part reveals the urban transformations occurred in the city from the description of the respective configurational properties from the point of view of Space Syntax.

2. READING CURITIBA: SPACE SYNTAX AS THEORY AND METHOD

The method of analysis adopted departs from historically situated urban contexts and develops from the relation between the characteristics of the morphological and functional elements and the configurational properties.

Space syntax was developed in the 1980s as a descriptive theory of space (Hillier and Hanson 1984). It proposes a fundamental relationship between the configuration of space in a city and the way that it functions. The analysis of the spatial configuration enables the identification of potential integration or segregation of each element in the system. These variables are calculated based on graph theory and, moreover, the actual morphological computation is based on the associated graph of the axial map (Hillier and Hanson 1984). The syntactic reading shows that integrated axes are the ones from which the other axes in the system are easier to reach. In average, they require shorter topological paths to be accessed from any axis in the system. These tend to assume dominant positions within the system, and to show higher numbers of pedestrian and vehicular flows.

The axial map is processed on Depthmap software (© UCL, 2010), in order to convert the city axes to a graph, that allows extracting both graphic and numeric outputs. The graphic output consists of an axial map with a colour gradation, in which warm colours represent more integrated axes, and colder colours more segregated ones. This process allows a direct comparison among the urban evolution maps, reducing them to a common basis. The cities of Curitiba and Lisbon were analysed in terms of their hierarchized structure, that is, their degree of topological accessibility. Axial maps and the values of global and local integration were chosen as analysis categories.

1 In the original text: “Entender o processo de crescimento urbano é importante porque nos oferece uma apreensão global da aglomeração numa perspectiva dinâmica. Ao revelar os pontos fixos de transformações anteriores, o estudo do crescimento permite determinar aquelas lógicas inscritas profundamente no território que esclarecem as razões de ser do assentamento atual. Começar a análise de uma cidade pelo estudo de seu crescimento é um dos meios de apreendê-la em sua globalidade, a fim de determinar o sentido a dar a estudos ulteriores mais detalhados.” (PANERAI, 2006, p.55)
The theoretical, methodological, and framework procedures of this piece of research were based on two points: (a) systematic collection of data and specific information, which assisted in the construction of the historical series of maps of the city of Curitiba; (b) production of axial maps from the base maps collected, followed by configurational analysis, taking the Theory of Social Logic of Space or Space Syntax as reference (Hillier and Hanson, 1984; Hillier, 1996).

In relation to the first point, the historical cartography of the city of Curitiba has a collection of more than fifty maps. They appear irregularly spaced until the 1960s, and, thereafter, there are annual records, with the gradual increase of new technologies, such as aero photogrammetry, and CAD databases, for example. Based on this panorama, six maps were selected following the criteria of completeness and clarity of information, and the capacity to demonstrate significant planning decisions.

The first one, from 1857, brings the record of the first existing urban configuration; the second one, from 1894, illustrates the growth of the city to the southern region and its configuration in the late nineteenth century; the third one, from 1914, shows the urban expansion of the beginning of the century, a period of significant economic growth; the fourth one, from 1935, shows the city before the first Master Plan, the Agache Plan, with macro characteristics in terms of urban planning; the fifth one, from 1962, records the transformations of the previous plan and represents a record of the city before the propositions of the SERETE - Wilhem Plan, a plan that changed the urban logic of Curitiba in terms of development in a significant way; and, finally, the sixth map, from 1988, consolidates the modifications of the previous plan, which was the last great intervention in structural terms, in the planning of the city.

The second point that based the methodology of this paper, that is, reading Curitiba from the syntactic analysis, aimed to reveal attributes of the Curitiba urban system in the selected historical maps. This system was evaluated for its hierarchical structures, or its gradation of topological accessibility. The evaluation criteria adopted for these readings were the axial maps, through their global and local integration value, using the Depthmap software.

When observing the sequential axial maps of a city, according to the pattern of the streets, it is possible to evaluate from the average "integration value" which period presented better or worse degrees of ease of displacement. Even more, it is also possible to note how the integration averages are transformed over time to the same urban nucleus, towards an urban network that is more favourable, or not, to the movement. From these measures, other variables of interest derive, such as the integration core, which consists of the set of the more accessible axes of a system, generally corresponding to the set of red lines. Such areas tend to coincide with the so-called active urban centres, that is, places where flows and distinct uses are converged in quantity and diversity.

In short, as a guideline of the analysis, the maps will be presented preceded by basic historical information linked to urban planning, and later, they will be appreciated according to the relations between history and axial maps. The map presentation will have the following sequence: at the top of the figures there are the integration maps, the global one to the left and the local one to the right, and at the bottom of the figures there is the historical map to the left, followed by a picture from the selected historical period.

3. HISTORY AND THE URBAN CONFIGURATION OF CURITIBA

Capital of the state of Paraná, Curitiba is geographically located in the southern part of Brazil and it has 1,746,896 inhabitants (IBGE, 2010). It is a city that, throughout its history has passed through a series of Letters, Codes of Postures and Master Plans that shaped its urban structure and its form of growth. Such Decisions, as already explained, left their records in the urban network and in the structuring of the city itself.

Curitiba was officially founded in 1693, when the city council was installed and the pillory was reinstalled. At that time, the city already had a central square with a church and only a few buildings in its immediate surroundings. It was elevated to the category of Vila in 1721, time in which the concept of city required by the Portuguese crown was implemented. However,
it remained stagnant for more than a hundred years, until its elevation to the Capital of the Province of Paraná, in 1854, a period in which the process of regular urban growth began and acquired a rapid increasingly rhythms as the twentieth century came. As it will be shown in the sequence of the text, the map of 1857 presents a city still undeveloped around its original nucleus (square and church), but it already had determinations in Book (created by the colonial official Ouvidor Rafael Pires Pardinho), and later by the Code of Postures of 1829 (developed by the inspector general of public lands Eng. Pierre Taulois) in relation to the necessary rectilinear alignment of the streets and their growth in orthogonal grid.

Constituting a city that still maintained a very close relationship with the rural area; the 1857 map shows the lines of only a few roads around the central square (Praça Tiradentes). This lines were formed by the connections of the city with the neighbourhoods, and still without visible concern related to its regularity (Fig. 01).

Figure 1 - Curitiba 1857 - At the top: Global and Local Integration Maps, At the bottom: Historical Map of 1857 and a picture of the Flowers Street, from approx. 1860 (current XV de Novembro Street).

It was obtained an average integration value of 1.67, with Carioca Street (1) being the most integrated one, (current Riachuelo Street). This street was one of the paths that connected the old and isolated village of Curitiba, recently transformed into capital of Paraná Province, to the coast, followed by Commerce Street (2) (current Marechal Deodoro Avenue). It was detected in this analysis a strong relationship of the 4 axial lines as being more integrated around the Tiradentes Square, forming a core of integration that merges with the founding nucleus of the city itself. Comparing the global and local integration maps, it can be seen that in the first one the most integrated ways were in the North-South direction, while the local integration shows dominance in the East-West axis. A local integration (HH3) that, due to the small number of streets in the urban nucleus of that time, keeps the Carioca Street (1) as the most integrated one followed by its transverses streets.

Following the historical process, one of the main inducers of the urban development of Curitiba was the Railway connecting the capital to the coast, Paranaguá – a port city. This connection was responsible for the disposal of agricultural products and supply of other products to the capital. The positioning of the Railway Station, inaugurated in 1885, about 800 meters south of the urbanized area, catalysed the growth, increasing the area between the Station and the City Centre (Dudeque, 2010) (Fig. 02).

Figure 2 - Implantation of the Curitiba Railway Station - Schematic Maps
Font: Adapted from Dudeque, 1995, p.161 a 165.
The development of this region was consolidated by the New Curitiba City Plan, from 1886 (developed by the Italian Engineer Ernesto Guaita). In this plan, the routes were proposed in the East-West direction, being perpendicular to the Railway Station, and, from them, the delimitation of an orthogonal grid for urban growth was established. The 1894 map already records the growth towards the south and the consolidation of the urban network that connects the founding City Centre. (Fig. 03)

At the end of the 19th century and beginning of the 20th century, the City Centre is consolidated as the most urbanized and dynamic area, and the growth lines that followed the roads responsible for connecting the mills gradually began to be structured and to receive urban improvements. As reported by Garcez (2006), in the south, near the railway station, the factories of beer, matches, power plants, processing industries, etc. proliferated. At that time, the “Flowers Street” (“Rua das Flores”, current XV de Novembro Street) (1), was consolidated as the city centre, being its main artery (fig. 03).

\[\begin{align*}
1894 & \\
\text{Global Integration (HH)} & \\
\text{Local Integration (HH3)} & \\
\end{align*}\]

*Figure 3 - Curitiba 1894 –At the top: Global and Local Integration Maps, At the bottom: Historical Map of 1857 and picture of the Flowers Street, approx. 1900 (current XV de Novembro Street). Font: Axial maps: Authors, Historical maps: IPPUC, 1857, Picture: Without author, 1900, filed in Casa da Memória.*
In the 1894 global integration map (Fig. 03), it can be observed that the most integrated street - Marechal Floriano Peixoto Avenue (2) longitudinally encompasses the orthogonal network of the system as a whole, connecting the centre to the station. This system of 97 axial lines, with an average integration value of 1.99, shows, in a certain way, that the current Barão do Rio Branco Street (3), which begins in front of the station towards the centre, does not have its importance materialized by the analysis. The core of integration, in this period, is practically represented by the Marechal Floriano Peixoto Avenue (2).

In a similar manner, in relation to the local integration, it can be noticed that the Marechal Floriano Peixoto Avenue (2) is still more integrated, followed by a parallel and a transversal street. It is observed that in both global and local integrations the more integrated pathways depict an orthogonal structure in elongated lines, linked to the central square (Praça Tiradentes - ground zero), but departing from that to a wider environment, also encompassing the Railway Station.

In the late nineteenth and early twentieth centuries, the immigration from European nations was intensified, increasing expressively the number of people in the city and in areas around the urbanized zone, beginning to create colonies in spaces that are consolidated districts today. As consequence, there was also a significant increase of infrastructure, with more structured public services for water supply, sewage treatment, telephony, lighting and urban transport service.

The increase in urban vitality can be seen in the picture of the Largo da Ordem in 1910 (Fig. 04), which shows a religious event and the eclectic architecture (in the centre).

Figure 4 - Curitiba 1914 –At the top: Global and Local Integration Maps, At the bottom: Historical Map of 1914 and picture of the Largo da Ordem, 1910.

The 1914 map already shows the consolidated growth to the west and south of the Railway Station, and it can be already seen the “stitching” of some points that still needed structuring in the previous maps. However, it may be also perceived the projection of a growth to the north of the city, a region not yet consolidated. The axial structure is consolidated in the orthogonality with a system of 205 axial lines. From these, the average integration value was 1.89 and the most integrated route was Visconde de Guarapuava Avenue (1), followed by Marechal Floriano Peixoto Avenue (2). Thus, we can perceive the result of the New Curitiba City Plan proposition, that is, there are more integrated routes to the south of the original nucleus area. In this period, The integration nucleus is represented by three axial lines, forming a cross. This formation ends up materializing the intention of Ernesto Guaita, regarding the East-West growth determined from the Railway Station. The local integration also strengthens the structure in cross, but in both directions: east-west and north-south.

The growth process led to the consolidation of the central area, with the Flowers Street (now XV de Novembro Street), being one of the most urbanized area. At this time, more precisely in 1919, in a further attempt to order urban growth, a new Code of Postures was approved. Among its determinations there was the delimitation of the city in three zones: The City Centre area, the Suburban area (in the surroundings of the centre) and the Rossio (rural area). Each of these areas should follow a specific regulation, mainly regarding the use and occupation of the soil. This moment is considered by some authors as the effective beginning of urban planning of the city. It was An era that was also marked by the concern with health issues arising from the growth (development of a preliminary plan for sanitation of the city by the Health Eng. Saturnino de Brito), which became even more evident in the middle of the century.

This city, which hardened its rules in a time when customs and even urban life were being consolidated, can be seen in the image of José Bonifácio Street in the 1920s (Fig. 05 – compared here with the map of 1927 because of its temporal proximity to Historical image - map not included in the syntactic analysis). The small road, next to the Cathedral, which dates back to the early days of the city, shows a great urban vitality at that time, with people walking down the street and sidewalks, groups talking under the awnings that are characteristics of the shops, carts carrying people, etc.

The result of these decisions can be seen in the 1935 map (Fig. 05). It demonstrates a greater density around the region formed by the historical centre and railway station, where the most integrated lines of the system occur. A dense and compact configuration can be observed, represented by 722 axial lines, with an average integration value of 0.65, and with the most integrated route being the Marechal Floriano Peixoto Avenue (1), followed by the Visconde de Guarapuava Avenue (2) and XV de Novembro Street (3). This historical moment is interesting because it represents, after the 1857 map, the only occurrence of a densification with so many lines with close and elevated integration values, characterizing a core, also dense, with great levels of connectivity distributed in a balanced way. In this time the core of formation - and, why not, the geometric center also - coincides with the topological core. As regards the local integration, it can be seen the formation of two topological sub-centers, east-west directions, connected by a third, the north-south (Fig. 05).
Figure 5 - At the top: 1927 Map and José Bonifácio Street, 1920s. Middle: Curitiba 1935 – Global and Local Integration Maps. At the bottom: Historical Map of 1935 and picture of the Hindenburg overflying the XV de Novembro Street, from 1936.

The urban denseness and the growth of the city, identified in the previous map, also brought a series of problems. In order to solve them, the French urbanist Alfred Agache was hired, who was already working in other Brazilian cities, to draw up a new Urban Plan. The structure proposed by him was based in the centre of the city as the radiating nucleus of a series of routes that connected this central area with the surrounding areas. These routes were classified as perimeter routes (bypassing the centre radially), radial routes (interconnecting the perimeter routes in the centre-neighbourhoods direction), and a diametrical avenue, crossing the city in the east-west direction. In addition, the Plan also established a series of Functional Centres (for example: civic centre, sports centre, commercial and social centre, industrial centre, etc.) each one following, as far as possible, functional vocations that were being developed through time in several areas of the city. Above all, Agache emphasized the identity of Curitiba, not very representative for a capital with the importance it was acquiring in the national scenario. The 1935 map showed a moment previous to the reforms proposed by the Plan. It was a city that, as we can see, was still compacted around its original enlarged nucleus, with some roads beyond these limits and connecting the city to the neighbouring municipalities.

As a practical result, the Agache Plan left some broad avenues, the Civic Centre in its planned place and the implementation of some radial avenues that ended up being the base of the subsequent Plan. The 1962 map (Fig. 06) shows these materializations and also demonstrates the great expansion of the urban grid in about 20 years, whose routes already exceeded the limits of 1935.

![Image of Curitiba 1962 showing global and local integration maps, historical map, and a picture of the "Boca Maldita".](http://curitibaantigamente.com/)

**Figure 6** - Curitiba 1962 – At the top: Global and Local Integration Maps, At the bottom: Historical Map of 1962 and picture of the "Boca Maldita", from 1967.

The axial map shows that the dense and compact configuration lost some strength, diluting the more connected routes to an extended environment, and better distributing the hierarchy between them. However, it still shows a relationship between the foundation core, geometric centre and topological centre. This system had 1254 axial lines, with an average integration value of 1.16. The Sete de Setembro Avenue was the most integrated street, with an axis increasingly strengthened, followed by the Marechal Floriano Peixoto Avenue and the Visconde de Guarapuava Avenue. The integration nucleus, in this period, reinforces the cross structure, a sign of the expansion of the urban network that was taking shape, but, the reading of local integration, besides reinforcing the centrality of the training centre, makes clear the formation of new sub-centres to the northeast and southwest.

In 1965, in the name of the outdated Agache Plan, after a competition among several companies, the company SERETE, with the participation of the architect and urbanist Jorge Wilheim, was responsible for the elaboration of a new Master Plan. The basis of his proposal was the transformation of the radial growth system into a linear growth, using the existent and structured roads by the previous plane routes (Fig. 07). In order to do so, it was proposed the densification along these axes, the known structural axes. In addition, it was sought the development to the southwest with the implantation of the Industrial City, relocating the previously area destined for that (in the southern region of the railway station).

The decisions of the SERETE-Wilhelm Plan, such as the strong densification around the North-South axis (much more consolidated to the south) and significantly in the East-West direction, are clear in the 1988 axial map (Fig. 08). The system now, almost ten times greater than the 1962 map, has 11509 axial lines, with an average integration value of 0.82, with the most integrated street being the Marechal Floriano Peixoto Avenue, followed by Sete de Setembro Avenue and Visconde de Guarapuava Avenue. These avenues play an important hierarchical role within the
system, representing great potential for movement. The core of integration, in this period, continues to present a structure in cross, but tending to consolidate it along its axes and, in a way, leading to the gradual detachment of the geometric centre with the topological cent.

It can be seen in Figure 08, in the Local Integration - HH3, there are nine points with a certain concentration of lines in red colour. These lines present significant attractiveness, defining, in fact, the hierarchical structure of the Curitiba system. Moreover, it reveals a high correspondence between the potential of the map and the actual situation investigated. It should be noted that, four “sub-centres” are located along the structural axes. These are the central axes within the planning conception of Curitiba; all of them are contemplated by terminals of integration of collective transport, where various types and sizes of services and trades are inserted.

As regards the two centralities - Bairro Sítio Cercado and Bairro do Cajuru, the regions that presented the highest values of local integration, are exactly the centres of commerce and services of these districts. In relation to the centrality of Alto do Rua XV de Novembro, it is a region in consolidation with a strong gastronomic vocation.

![Figure 8 - Curitiba 1988 – Global and Local Integration Maps.](#)

Font: Authors.
With the urban limits practically consolidated, the interventions in the next years were practically restricted to some larger constructions, with more symbolic than structuring content in terms of the urban network. What is perceived, in this case, is only the densification of some regions of the city, which can be seen nowadays.

4. URBAN TRANSFORMATIONS IN THE LIGHT OF SPACE SYNTAX

In a way, the growth of the urban area of Curitiba City maintains a certain regularity in terms of territorial expansion, presenting two moments of break, in which this territorial expansion occurs in a more accelerated way. As shown in Figure 09, the first break occurs with the implantation of the Railway Station, a planned growth induction (spots 1857 and 1894). The second moment of great expansion already appears in the most recent history of the city, in the period of implantation of the SERETE – WILHEIM Plan (spots 1962 and 1988).

Figure 9 - The evolution of the urban area of Curitiba.


Taking these specificities into account, and in order to analyse only the syntactic characteristics of the city of Curitiba, we aim at comparing the core of global and local integrations over time. For In order to reach that, we elaborated a table (Fig. 10), presenting a comparison between the amount of axial lines; size and shape of the integration core and the identification and position of the sub-centres (local integration) in each cited period.
When Comparing the transformation of the cores of global integration over time we can see some interesting transformations. In 1857, this nucleus is positioned around Praça Tiradentes, the ground zero of the city, but in 1894, it stretches towards the Railway Station, and later, the east-west axis is formed, leaving the nucleus of integration with the shape of a cross in 1914. In 1935, there is already a resumption of a greater urban centrality, but with an enlarged centre, unifying the historic centre and the Railway Station. It is Interesting to observe that the Agache’s

<table>
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<th>Year</th>
<th>Space Syntax</th>
<th>Global Integration Core</th>
<th>Local Integration Core</th>
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<td></td>
<td>average integration value: 1.67</td>
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<tr>
<td>1894</td>
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<tr>
<td></td>
<td>average integration value: 1.99</td>
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<td><img src="image6" alt="Diagram" /></td>
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<td></td>
<td>average integration value: 1.89</td>
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<tr>
<td>1935</td>
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<td></td>
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<tr>
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<td></td>
<td>average integration value: 1.16</td>
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<td>1988</td>
<td>number of axial lines: 11,509</td>
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<tr>
<td></td>
<td>average integration value: 0.82</td>
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</table>

Figure 10 - The comparison of size and shape of the Global and Local Integration Core of Curitiba – 1857; 1894; 1914; 1935; 1962 e 1988.

Font: Authors.
proposal is based on this more centralized city configuration. However, in 1962, shortly before the SERETE-Wilhelm Plan, the city was once again with the cross-shaped integration core. In 1988, the nucleus of integration continues in a cross format, but a breakdown in this format is already perceived, beginning to dissolve, or in another way of looking at it, returning to a greater concentration, as occurred in 1857 and 1935.

The centrality does not have very a clear limit. As time goes by, the centrality changes place, size and form, sometimes expanding or sometimes retracting. In Curitiba, the core of local integration presents such behaviour, with more grouped lines only in the 1857 map. After this date, the tendency to become a cross with balanced arms can be clearly seen in the 1894 to 1962 maps. However, in 1988 there is already a disarticulation of this form, with the formation of displaced sub-centres in the cross organization.

In the comparison between the global and local integration cores of each epoch it may be perceived a certain similarity in almost all the periods. But, it is interesting to note that in 1894 there is a greater differentiation in relation to both integrations, because, the nucleus of local integration tends to structure a sub-centre to the east, which ends up consolidating and becoming linked to the global integration core of the 1914 map. This situation also occurs with the local integration core of 1935, differently from the global integration of the same date, but similarly to the later global integration core, of 1962. In both cases it seems that the core of local integration ends up being the harbinger of what would happen in the city globally.

5. FINAL CONSIDERATIONS

The use of spatial syntax to analyse the urban expansion of Curitiba allows the interpretation of other dimensions of space, that is, the hierarchy of the paths from the potential of flows, which surpasses the information found in conventional mapping. The six axial maps resulting from the linear representations of the historical maps of Curitiba allowed the visualization of the accessibility arrangements and its articulations.

When observing the sequences of global integration maps over time, it is possible to record some important findings for the reading of the urban historiography of Curitiba:

• The growth of the urban network between the periods of 1962 to 1988 was about ten times, much higher than the average of previous years, when the city increased from two to three times the existing network;

• The most connected lines of the system, since the end of the nineteenth century, tend to the densification in the east-west and south axes, losing this relation only for a short time, represented by the map of 1935, in which the densification is more compact in the surroundings of the centre-railway station;

• The northern region is little connected to the city, a situation that becomes clear when we observe the nucleus of global integration of 1962, with the north axis more elongated and connected with the central area;

• Despite the growth trend of Curitiba to the south, only one route in this direction remained in the integrating nucleus of the city in all periods: The Marechal Floriano Peixoto Avenue (Fig. 07);

• The implantation of the railway station in 1885 (Fig. 09) changes the positioning of the integrating nucleus, initiating a growth towards the south of the capital. As a result of that, Ernesto Guaita’s Plan to densify the city in a checker grid based on the north-south and east-west axes, starting from the Railway Station, seems to be consolidated in the 1935 map, the last one in which the integrating nucleus appears denser;

• Some roads that appear only once in the integrator core had the potential to become new connection axes, but were ignored.
The structure in Axes proposed by the SERETE-Wilhelm Plan in 1965 already existed if we analyze the core of global integration of the map of 1962. In this sense, it should be noted that its proposition followed a trend that was already implanted in the urban scenario. Such proposal, in 1988, already begins to demonstrate the loss of rigidity of these axes as organizers of the urban growth with the emergence of sub-centres that seem to be independent of the macro axes of city development.

If we look at the grid of the Curitiba city of 1988, very close to the present, we have identified that the most important decision for its structuring was the construction of the railway station in 1885. With the intention of developing the southern portion of the urban nucleus, the consequence, besides the initial objective, was the creation of the main development axes in the east-west direction. In addition, by the dimension of its occupation in the block, it also served as a driver of the north-south axis.

This linear organization of the city was lost only in one moment, in the map of 1935. By reading this condition, Agache proposed an intervention by radially strengthening the urban centre and the densifying towards its edges. Its plan, not realized in its essence, could have modified the urban lines of Curitiba to the present day. That is, we would possibly have another predominant urban structure.

The urban reading carried out by the SERETE-Wilhelm Plan, in 1965, resumed the linear situation of the railroad and strengthened it. This occurred with the consolidation of the north-south and east-west axes through urban transport, and of planning decisions that proposed verticalization, and population densification, along its borders. This situation has been increasingly solidified by IPPUC interventions from the 1970s to the 1990s, with the implementation of the “ligeirinho” (bus system faster than a normal bus line due its few stops) and, later, biarticulated buses and tube stations (simulation of a subway station on street level). Nowadays, due to the dimensions of the urban grid, the growth in axes has already lost its force in points farthest from the central area.

The methodology adopted proved to be adequate for the explanation of the theme and the available data, since, it was able to include, both in quantitative indexes and graphically, the particularities and permanencies of the evolution of the Curitiba urban network. This study, therefore, strengthens recurrent space-shape research, but will also contribute to the exercise of new questions. In addition, a number of issues can still be addressed in relation to the comparison between the planners’ intentions and the resulting city few years later.
REFERENCES


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NATURAL MOVEMENTS IN PREHISTORIC VILLAGES?

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ABSTRACT

Hillier and other researchers combined analysis of urban grids using axial maps with counts of pedestrian movements. They recognised the influence these grids played on pedestrian movements in cities and developed the ‘law of natural movement’ in which urban grids are principal generators of pedestrian movement and starting point for a city’s development into specialised ‘generative’ and ‘conservative’ zones.

In archaeology, tree ring dating has allowed to analyse growth processes of prehistoric villages. This paper looks at some of these settlements in the Circum-Alpine region using axial maps. It analyses how new buildings fitted into emerging street patterns.

Contrary to modern economies, it remains extremely difficult to determine in prehistoric settlements what could be considered equivalent to modern ‘movement-rich land uses’ to further explore the ‘law of natural movement’. However, there are signs of changing and increasingly specialised economies in the second half of the 4th millennium BC. Also within certain settlements, there are occasions in which ‘not normal buildings’ were added respectively different settlement sections used for specific purposes.

The paper cannot provide new inputs into the ‘law of natural movement’ as such but gives ‘spatial-based’ arguments to the discussion of social changes during the transition from Neolithic to Early Bronze Age.

KEYWORDS

Axial maps, Natural movement, Archaeology, Neolithic, Bronze Age

1. INTRODUCTION

In 1993, Hillier et al. combined the analysis of urban grids using axial maps with counts of pedestrian movements. They recognised the influence urban grids played in generating pedestrian movements in cities and developed their ‘law of natural movement’. It identified urban grids as the principal generator of pedestrian movement and starting point for a city’s development (Figure 1). In subsequent steps, movement-rich businesses such as e.g. retail sector tend to be allocated along well-integrated axial lines, while lesser lines are typical for residential areas. With this feedback loop, cities develop into specialised ‘generative’ respectively ‘conservative’ zones as outlined in a series of further research (e.g. Hillier 1996, 2001 etc.).
2. DATASETS AND METHODS

Tree ring dating, as the most precise dating method in archaeology, has recently allowed to analyse growth processes of prehistoric villages. In optimal cases with preserved wanes on structural remains and oak as construction material, accuracy of tree ring data can be within half a year. However, in most cases felling dates of trees used to build these settlements remain within approximately a year. Still, this allows to fairly accurately follow the construction and repairs of even single houses.

This paper therefore aims to combine archaeological and Space Syntax methods to look into the development of selected villages in the Circum-Alpine region (Figure 2). It wonders, whether the transition from Late Neolithic (late 4th millennium BC) to Early Bronze Age (1st half of 2nd millennium BC) brought forward spatial configurations in which similarities to ‘natural movement’ in modern cities can be traced. However, since the ‘law of natural movement’ is related to economic structures of a city, the paper will first take an introductory look at economic aspects of the time in question.

The second half of the 4th millennium BC was marked by important economic changes. They are seen as reactions to an unfavourable climatic period between 3400 and 3000 BC when temperatures in central Europe were about 1-2 °C lower (Amesbury et al., 2008; Bleicher and Sirocko, 2010). These new technologies were primarily aimed at facilitating food production.

Increased food production was achieved by exploiting less yielding soils and ‘mechanising’ production. Disk wheels were found in Zurich (Ruoff and Jacomet, 2002) and at Lake Feder, South Germany (Schlichterle, 2002) dating to mid 4th millennium BC. Furthermore, cattle drawn carts increased transport capacities (Deschler-Erb et al., 2006; Leuzinger, 2002). From 3400 BC onwards appeared spindle whorls in large numbers. These corresponded to the introduction of new flax varieties, produce of which e.g. the villages of Alleshausen-Grundwiesen and Seekirch-Achwiesen, Germany were specialised (Maier, 2004, p. 105–106, 123).
In the course of this paper, spatial configurations will also be abstracted using elementary syntaxes developed by Hillier et al. in the very nascent state of Space Syntax (Hillier et al., 1978, p.372–373; Hillier and Hanson, 1984, p.78) although rarely used in archaeology (e.g. Banning, 2010). This allows to identify common genotypic features otherwise over-shadowed by phenotypic differences.

2.1 ‘XX O Y-CONFIGURATION’ DURING CORTAILLOD CULTURE (3900–3500 BC)

The axial line map of Sutz-Latrigen, Hauptstation innen SW [south-west] with its overall configuration of ‘Y o X (XX o y)1 ... (XX o y)n o y’ shows most integrated axial lines along its central lane between two rows of main buildings as well as in open spaces between them and their corresponding auxiliary buildings (Figure 3, left). Least integrated axial lines run perpendicularly to the former and separate building pairs.

An interesting insight into the social organisation of Cortaillod Culture lakeside settlements offers the marking of trees growing in the surrounding forests. Trees suitable for later construction purposes were marked by their individual owners with adze marks. These trees were later felled and used e.g. for house repairs. However, should the need arise, such ‘private ownership’ could be overridden and respective ‘privately reserved’ trees used for ‘communal purposes’ such as building wave breakers around the villages (Pillonel, 2007).

In this socio-cultural context, least integrated axial lines of Sutz-Latrigen, Hauptstation innen SW most likely indicated different lots of individual households within the village. Such interpretation is further supported by elevated walkways linking individual main- and auxiliary building pairs in the younger but almost congruent sites of Murten-Pantschau (3428–3418 BC; Mauvilly, 2015) and Sutz-Latrigen, Riedstation (3393–3389 BC; Stapfer et al., 2016, p.29, Abb. 15).

In the last quarter of 4th millennium BC, the western part of Switzerland came under increasing influence from developing Early Horgen Culture.
2.2 ‘XY-CONFIGURATION’ OF EARLY HORGEN PERIOD (C. 3400/3300–2800 BC)

Horgen Culture emerged in Eastern Switzerland and South Germany at around 3400/3300 BC. Typical for this culture was a rough, low fired pottery. Wide spread spatial configuration of Early Horgen Culture villages were almost chess board-like arranged ‘primary cells leading onto open spaces’ of narrow lanes (‘Xy-configuration’ or z3).
The spatial influx of developing Early Horgen Period can be seen in Sutz-Lattrigen, Hauptstation at Lake Biel/Bienne. The village seems to have at first followed the spatial ‘XX o y-configuration’ of Cortaillod Culture (Figure 4, left). Good visible in this stage (3202–3182 BC) are the most integrated axial lines along the house front and what was supposed to become the future central lane. The only difference at this stage to the Cortaillod Culture configuration discussed above was the central lane now oriented perpendicularly to the shoreline (compare with Figure 3).

Figure 4 - Sutz-Lattrigen, Hauptstation and its ‘over print’ through the influence of Early Horgen Culture.
However, with new houses of uniform size being built from 3272 BC onwards and until 3138 BC, the settlement was completely overprinted with the ‘Xy-configuration’ of Horgen Culture (Figure 4, right side series). The integration core shifted parallel to the shoreline and open spaces within the village centre were replaced by narrow lanes. Integration was rather uniform with a high ‘intelligibility’ index of R²=0.97. Only a remaining stretch of the initial palisade created a more segregated section in the south-western corner of the settlement.

Another thoroughly investigated village of Early Horgen Period is Arbon-Bleiche 3 at the southern shore of Lake Constance. Tree ring data of every single structure allow a detailed view into this village’s development, which started with a ‘pioneer building’ erected in 3384 BC (Leuzinger, 2000, p.158–161). New houses were added almost annually for another seven years before the entire village was destroyed by fire in 3369 BC (Figure 5).

Axial line analysis reveal how the spatial configuration followed a pre-defined pattern throughout the village’s development. The most integrated axial lines stayed along the eastern lane leading towards Lake Constance. A shallow terrace edge resulted in a slight off-set of building alignments and separated a more landward northern section from a less integrated, lower laying southern part.

Striking in the case of Arbon-Bleiche 3 is that in 3379 BC respectively one year later, two small houses were added along the most integrated axial lines (Figure 5, black shaded). These were much smaller and are not considered normal residential buildings. Economic purposes are discussed but neither their construction technique nor finds distribution reveal what for or by whom these buildings were used (ibidem, p.78–79, 85).

Different aspects allow a glimpse into the social organisation of Arbon-Bleiche 3. The slight horizontal offset in the building rows is reflected in their inhabitants’ diets. People living in buildings on the terrace consumed more meat while those in the lakeside part turned more to fishing (Marti-Grädel et al., 2004,p.173, Fig. 15 and 16).

Arbon-Bleiche 3 had also long-distance contacts along the River Danube. These reached as far as the area around today’s Vienna as forms of pottery vessels originating in those areas but made locally illustrate. It is therefore discussed, whether two groups with different cultural backgrounds lived together in Arbon-Bleiche 3 (ibidem, p.175).

2.3 STRONGER SPATIAL CONTROL DURING LATE HORGEN PERIOD?

During Late Horgen Period (last quarter of 3rd millennium BC) a number of lakeside settlements emerged following a particular spatial configuration. Common was a central, ‘jetty-like’ elevated access way with perpendicular standing houses on both sides (Figure 6, top).

Settlements at Lake Constance following this configuration were Sipplingen-Osthafen (2917–2855 BC, Billamboz et al., 2010) and Allensbach-Strandbad (Fischer, 2006). The same configuration was also found in the Swiss Midlands (e.g. Horgen-Scheller (Achour-Uster et al., 2002, p.118); Sutz-Lattrigen, Kleine Station (2756–2754 BC, Hafner and Suter, 2004, p.22) and Sutz-Lattrigen, Rütte (2726–2704 BC, Suter and Francuz, 2010). However, despite being often included, Seekirch-Stockwiesen (Schlichtherle, 2004, p.22–33) does not belong to this category of “Strassendorf” [street village] since its walkway was at ground-level and more open space available beside it.

The overall ‘walkable’ interaction space of these village proves difficult to reconstrukt. At Sutz-Lattrigen, Rütte (2726–2688 BC; Figure 6, bottom) e.g. beams supporting house floors may have protruded irregularly from these stilted houses. While these may not have constituted a ‘walkable’ surface along building sides, they must have supported connections linking buildings and central walkway. However, constructions of these links cannot be determined and may have been anything from a single plank to a forecourt as part of the houses themselves.
Figure 5 - Development of axial lines in Arbon-Bleiche 3.
Therefore, fewest line axial line map of Sutz-Lattrigen, Rütte shows most integrated axial lines along the central walkway (Figure 6, bottom). In extreme cases, the resulting integration core of these villages may have consisted of a single axial line running along a narrow central walkway. Interesting in these lakeside settlements is further their lack of sufficiently big open convex spaces for gatherings of large groups. The principal of the ‘XY-configuration’ or ‘houses leading to open spaces’ discussed for Early Horgen Period was further reduced to ‘all buildings leading to one shared open space’. Their jetty-like access ways were merely for movement. Therefore, although being in good locations to serve as ‘inhabitant-stranger-interface’ (Hillier and Hanson, 1984, p.121–122), such function of central walkways has to be questioned as their width-length-ratios were most unfavourable to encourage such interactions.

The end of Horgen Culture was marked by the emergence of the Pan European Corded Ware Culture (c. 2900–2350 BC). Recent DNA-analysis revealed that Corded Ware Culture was genetically strongly related to Yamnaya Culture and may be the result of large-scale migrations from Eurasian steppes towards west (Haak et al., 2015; Kristiansen et al., 2017).

Figure 6 - Artist impression of Sipplingen-Osthafen (top; Fischer, 2006, p.39, Abb. 42) and Sutz-Lattrigen, Rütte fewest line axial line map (bottom).
2.4 SPATIAL ‘RESET’ DURING CORDED WARE CULTURE?

Typical for Corded Ware Culture was their gender specific burial practice. Both genders were buried in a flexed position facing south but with men resting on their right side and women on their left (Figure 7, left). These burials may also suggest a different ‘space-time-identity’ of society (Porshansky et al., 1983), which found its expression in new settlement configurations.

Spatial configurations of many Corded Ware villages showed a pattern similar to previously illustrated Early Horgen period settlements. Houses were again arranged in more loosely but still orthogonal grids. More detailed axial line analysis allows e.g. the Corded Ware phase of Zurich-Mozartstrasse (Figure 8).

No pedestrian counts can be conducted in prehistoric settlements. It also remains in Zurich-Mozartstrasse impossible to identify equivalents to modern retail businesses. However, a correlation between strong integrated axial lines and expected pedestrian movements can be concluded indirectly.

In Zurich-Mozartstrasse, a great number of thin round willow posts were unearthed (Figure 8, bottom right). Although construction details remain unknown, these posts are interpreted as possible supports of an elevated walking surface (Bleicher pers. communication; Ebersbach et al., 2015, p.162). However, the cumulated number of these largely un-dated posts corresponds well with the most integrated axial lines at the last stage of the village in 2598 BC.

During Corded Ware Culture (c. 2900–2350 BC) – and almost as a kind of ‘contra-concept’ – emerged Bell Beaker Culture (c. 2800–1800 BC). With this culture developed a possibly very different spatial concept of their settlements.

2.5 BELL BEAKER CULTURE WITH A NEW SPATIAL CONCEPT

While Bell Beaker Culture is widely known through its gender-specific bipolar burial practice and distinct bell-shaped drinking cups (Figure 7, right), knowledge of settlements remains vague. To date, only Cortaillod, Sur-les-Rochettes-Est, Switzerland (von Burg, 2002), Kloibikau, Saxony-Anhalt, Germany (Balfanz et al., 2015) and Castenaso, Italy (Cadeddu et al., 2011) have revealed results allowing to use Space Syntax.
Cortaillod, Sur-les-Rochettes-Est was a small settlement with five houses (Figure 9). Distances between buildings varied from 10–15m or between 1–1½ house lengths (von Burg 2002, p.52, Abb. 60). These were about the same relative distances as in Castenaso (Bologna), Italy (Cadeddu et al., 2011, p.635, Fig. 2). With 50m or twice the building lengths even greater relative

Figure 8 - Development of axial lines in Zurich-Mozartstrasse, Corded Ware Period.
distances were found in Klobikau, Saxony-Anhalt, Germany (Balfanz et al., 2015, p.750, Abb. 3 and p.751, Abb. 4). Therefore, the spatial concept of Bell Beaker settlements may cautiously be described as an ‘open space containing a primary cell’ or ‘y o X-configuration’. However, some houses in «Derrière-le-Château» (Géovreissiat et Montréal-la-Cluse, Ain (France) may have stood closer (Besse, 2003, p.25, Fig. 8b).

This spatial description as ‘y o X’ is in contrast to the ‘Xy-configuration’ (‘a primary cell leading to an open space’ or z3-syntax) but may be justified as there are indications that these open spaces between houses played an important role in the ‘space-time-identity’ of Bell Beaker people. Such importance can be assumed from the fact, that in Cortaillod buildings 4 and 5 were rebuilt as houses 6 and 7 while keeping their respective original locations even though no spatial constraint could be found to do so (von Burg, 2002, p.52, Abb. 60). Location-constant rebuilds can e.g. also be found in Late Horgen Period settlements of Hünenberg-Chämleten ZG, Strandbad (Switzerland; Hafner et al., 1996, Abb. 109; 110) and Allensbach-Strandbad (Germany; Fischer, 2006, p.38) but with much smaller open spaces in between.

Figure 9 - Bell Beaker settlement of Cortaillod, Sur-les-Rochettes-Est, Switzerland.
The fewest line axial line map of Cortaillod, Sur-les-Rochettes-Est reveals a rather disperse integration core away from the building cluster (Figure 9, top). Using the whole settlement terrace to generate an ‘intelligibility’ scatter gram, axial lines within the building cluster and such from its environment resulted in a very coherent point cloud. This continuity in the scatter gram renders the settlement ‘readable’ even from its surrounding. Consequently this Bell Beaker village somehow ‘disintegrated’ and ‘became part of its surrounding’, an observation with far-reaching implications as later will be discussed.

Striking in the case of Cortaillod is the influence of a group of big boulders north-east of the building cluster (Figure 9, bottom). Even though their cultural significance is unknown, they concentrate the integration core and shift it further away from the buildings. The dominance of these boulders also distorts the ‘intelligibility’ scatter gram completely. Compared to the rest of the hill terrace the settlement was built upon, the location of the buildings themselves is rendered by these boulders to one of the less integrated parts. As a result, the wide scattered building cluster of Cortaillod and the more prominent features in its vicinity ‘weakened’ the settlement’s grid and its ability to generate movement.

This dispersal into smaller, and possibly more autarchic, Bell Beaker units are also reflected in other studies and can e.g. be traced on an economic level as Lechterbeck et al. worked out for the Western Lake Constance region (2013).

2.6 EARLY BRONZE AGE – SPACE AS PART OF TRADE NETWORKS

More dense spatial settlement configurations can again be found during developing Early Bronze Age in the first half of the 2nd millennium BC. This period was influenced by the emerging copper-tin-metallurgy. Due to spatial scarcity of the main alloy components copper and tin, trade networks formed, spanning the entire European continent. These networks were in the hands of influential and wealthy ‘elites’.

The influence metal trade networks may have had, can be seen in the spatial configuration of certain lakeside settlements. One example is Concise-sous-Colachoz at Lake Neuchâtel, Switzerland with its most complex and extended phase E12 between 1645 and 1619 BC.

Axial line analysis of Concise-sous-Colachoz, phase E12 was conducted with neighbouring stilted houses and elevated central walkway interconnected, thus resembling a multi-room building (Figure 10, top). With access to all parts of the settlement allowed, most integrated axial lines concentrated on the elevated central access way to the living quarters within the inner palisade ring. Integration was equal within houses of each row but decreased towards Lake Neuchâtel. However, access to this walkway was most likely controlled by a ‘special structure’ next to the inner palisade (black shaded) and therefore possibly restricted (Spring, in print).

In case, access to the village centre was denied, most integrated axial lines shifted towards the western part of the beach platform between inner and outer palisade ring (Figure 10, bottom). They concentrated around three houses standing perpendicularly to the rest of the buildings (grey shaded). Very obvious for today’s archaeologists, isovist analysis reveal that these buildings could not be seen by a prehistoric visitor coming from landside. On the other hand, they were prominent features when arriving by boat across Lake Neuchâtel. Next to these houses was the only big convex space available for large group interaction, while the elevated walkway was merely for movement.

Insight into the social organisation of Concise-sous-Colachoz, phase E12 give distribution analysis of vessel remains. These showed that groups with different regional trade connections lived in the village. Some may have come from Eastern Switzerland, while the ones residing on the opposite side of the walkway had connections to the French Jura region (Burri-Wyser, 2013, p.306).
Early Bronze Age settlements with a similar two-partite spatial distinctions were Sévrier-Les Mongets at Lake Annecy, France (Billaud and Marguet, 2005, p.176, Fig. 5a) and Zurich-Mozartstrasse, phase C1A, Switzerland (Schmidheiny, 2011, p.79–90).

The first part of this paper looked at spatial configurations of Late Neolithic and Early Bronze Age villages. However, the author is obliged to admit that his initial aim to trace developments which could be compared with the ‘law of natural movement’ conceptualised by Hillier et al. could not met. To make up for this deficit, it is necessary to include further archaeological and socio-spatial aspects to find answers why this failed.

3. RESULTS

The previous part of this paper looked at spatial developments of prehistoric settlements between 2nd half of 4th and mid 2nd millennium BC. One remaining problem to trace the ‘law of natural movement’ in these settlements is their relatively short live span. The use of open fires in wooden houses covered in reed posed a constant fire hazard and far too often resulted in devastating incidents. However, natural science and spatial analysis allow a glimpse into social and economic organisation of these societies.

Interesting to notice is the rather strict spatial configuration – almost some kind of ‘cultural fingerprint’ – during Cortaillod Culture in western Switzerland. With the recurrent growth pattern of ‘a pair of houses including an open space in between’ (‘XX o y-configuration’) it could be argued that these open spaces were ‘private’, while the central lane e.g. found in Sutz-
Lattrigen, Hauptstation innen SW (Figure 3) and only suitable for movement, could be seen as 'public space'.

Arbon-Bleiche 3 was discussed for its two special structures along most integrated axial lines (Figure 5). It remains impossible to attribute these structures to anything comparable to retail businesses in the widest sense. However, pottery remains indicate long-distance contacts down the Danube River and suggest inhabitants of different origins and with various organisational strategies living together at Lake Constance.

Already in Early Horgen Period during the last third of 4th millennium BC, open space within settlements seems to have been reduced to narrow lanes only suitable for movement. Convex gathering space, important for reproduction of society has to be expected outside villages. However, those areas are seldom excavated due to financial restraints as well as political pressure, and may not reveal much structural remains.

In Late Horgen Period (beginning 3rd millennium BC) many lakeside settlements saw their integration core reduced to almost a single straight line. Indications of a reclusive society can also be found in the limitation of imports from other areas. During this period many villages were built onto hilltops or hill promontories (Biel, 1987). Although none of them is suitable for more detailed Space Syntax Analysis, their defining segregating outline, further underlines a more reclusive background of their construction.

Space Syntax has provided comprehensive studies into spatial configurations and power structures (e.g. Markus, 1993). While these Late Horgen Period settlements reveal justified graphs comparable to prisons, there is no archaeological evidence of any central decision taking authority. However, the residential buildings are all dead-end-spaces with the same 'programmatic label'. Therefore, these villages followed a 'strong program' in how their social script was embedded in space through a pattern of distribution, affordances and labelling (Capillé and Psarra, 2014, p.24). But what was the reason for their inhabitants to live there in the first place?

Latest DNA results indicate large scale migrations from the Pontic-Caspian steppe towards western Europe. Furthermore, a decline in Neolithic activities around 3000 BC could indicate a social crisis (Kristiansen et al., 2017). Even an early form of plague (Rasmussen et al., 2015) may have triggered such reclusive reactions.

Although ‘prehistoric information propagation’ of such events and resulting psychological reactions of the recipients cannot be reconstructed, the author thinks, that ‘fear’ can be assumed as one. Consequently, inhabitant-stranger-interactions may have been controlled and could well have taken place on dedicated locations outside settlements.

A symbolic link between living quarters and their surroundings during Late Horgen Period can be found in Sutz-Lattrigen, Kleine Station (2849–2754 BC). This lakeside village had a central access way pointing straight towards a huge cup-marked boulder on dry land (Hafner and Suter, 2004, p.22, Abb. 8). If inhabitant-stranger-interactions indeed took place ‘extra mural’, the ‘law of natural movement’ would not be traceable within Late Horgen Period settlements.

Little new input on spatial configurations could be traced during Corded Ware Culture (in Switzerland c. 2750–2400 BC). The spatial layout of e.g. Zurich-Mozartstrasse seems to appear almost as some kind of ‘reset’ to Early Horgen Period level.

The migration background to the emergence of Corded Ware Culture has previously been explained. Strontium isotope, genetic and dietary analysis on skeletal material suggest for a time slot parallel to Zurich-Mozartstrasse high mobility and “stable female exogamy” in Corded Ware societies of southern Germany (Sjögren et al., 2016, p.27/33). Although some of these women came from non-Corded Ware groups (ibidem), it would on the ‘receiving end’ call for
'sufficiently permeable' Corded Ware settlement configurations to encourage encounters, which could explain this 'spatial reset'.

On the other hand, fundamental changes occurred during Bell Beaker Phase (c. 2900–1800 BC). Although the current data base leaves much to wish for, spatial configuration of this phase seems to have been somehow 'reversed'. Striking are great distances between buildings. These were at least the length of a building apart, while in Horgen Period only narrow lanes separated houses.

Particular care seems also to have been taken to keep open spaces between Bell Beaker buildings when houses were rebuilt. Therefore, the recurrent growth process of these settlements could best be described as 'a primary cell within an open space' or 'y o X-configuration'. Possible keys to this particular spatial behavioural can be found on different levels, of which some have started much earlier.

During the 28th century BC existed several long lasting villages parallel in the same micro region of Lake Biel/Bienne (Hafner and Suter, 2004, p.20) and Lake Constance (Billamboz et al., 2010, p.265, Abb. 7). These villages were in viewing distance from each other and are likely to have caused an augmented awareness of co-presence. While large open grassland did not yet exist in the hinterland of Lake Constance (Lechterbeck et al., 2013, p.12), this increased awareness of co-presence along lake shores may not only have encouraged interactions but, in stress situations, also increased competitive fears among different groups. As a result, an enhanced ‘group awareness’ may have developed.

Added to this, houses were now more often repaired and renovated. During 35th century BC, several attempts to found new villages around Lake Biel/Bienne failed and houses were abandoned shortly after being constructed (Hafner and Suter, 2004, p.16, Abb. 2; 17, 18). In the 28th century BC existed villages over three or four generations (e.g. Vinelz-Hafen, 2774–2701 BC; Hafner and Suter, 2003, p.29) and buildings were maintained of longer periods (Suter and Francuz, 2010, p.202), house 2 in Saint-Blaise/Bains des Dames, Switzerland even over a century (Gassmann, 2007). Therefore, people having grown up in such long-lasting houses may have developed a personal ‘space-time-identity’ closer related to these buildings and handed it down during the socialisation of their own descendants.

Corded Ware Culture introduced from 28th century BC onwards with its burial practice of single graves – at least on a gender level – a new concept of ‘self identity’ or ‘individualism’ in the widest sense. Even though there were differences between these two culture, aspects of ‘self identity’ developed further among Bell Beaker people and can best be seen in their children’s graves. Even burials of very young children already followed the adult practice of gender-specific, bipolar inhumations (Figure 7). It is therefore discussed, whether Bell Beaker children were born into pre-destined roles of e.g. man/woman, husband/wife, etc. (Nadler, 2006; Turek, 2000).

In these changing social contexts, also the primary cell of a house would play an important part. It may transform its role from ‘a simple shell’, which provided shelter from the inclemency of the weather, to a physical symbol of a social entity – we may call ‘family’ or ‘clan’ in the widest sense – for which the house it occupied was the physical manifestation (Coudart, 1999, p.537).

This tangible symbol of ‘family’ would consequently have to be ‘displayed’ by its inhabitants to mark their distinction to others. Therefore, the open space surrounding Bell Beaker houses previously discussed had to be maintained and distances kept to neighbouring buildings. Such distinctions would occur until the understanding of ‘family’ had become an established part of ‘space-time-identity’ in the entire society.
Indications of when the concept of ‘family’ may have been entrenched in society are individual burials arranged in grave groups. Such burial groups can be distinguished at the transition from Bell Beaker Culture to developing Early Bronze Age period. Graves e.g. in Singen, Nordstadtterrasse, Germany (c. 2150 BC) still followed the Bell Beaker pattern of flexed bipolar inhumations but were arranged in different groups (Krause, 1988; Stockhammer et al., 2015, p.20).

Such burial arrangements shifted the focus from the still relatively fleeting duration of settlements to more ‘generation-spanning’ environments of cemeteries. It consequently ‘freed’ the spatial configurations of Early Bronze Age settlements from the ‘obligation’ of keeping distance to neighbouring buildings and ‘allowing’ to return to clustered villages. Earliest Early Bronze Age settlement at Lake Constance revealing such configuration was Bodman-Schachen I, Bauphase 1 with nine buildings in two irregular rows and radio-carbon dates of the 19th century BC (Königer, 2006, p.94 and p.95, Abb. 85).

In later Bronze Age periods and with the idea of ‘family’ or ‘clan’ further developing, grave clustering in huge burial mounds became a more dominant expression of social structures. Such widening familial relationships and social differentiation with more or less successful agents, as well as resulting contractual dependencies, eventually formed the basis for the development of bigger political and economical entities across Europe.

And from an archaeological research point of view, the ‘y o X-configuration’ of Bell Beaker settlements may actually hold the key why no lakeside settlements of this culture have been found so far. Although the author does not want to exclude this possibility, Bell Beaker settlements following a ‘y o X-configuration’ and built onto beach platforms or into lakes themselves, would most likely have consisted of single houses built in considerable distance to each other and being connected to dry ground by individual elevated walkways. However, to identify such structures it would be necessary to survey large underwater areas and tree-ring date each and every single wooden post. To identify more Bell Beaker settlements, the author argues that it may therefore be necessary to abandon the idea of ‘typical clustered villages’.

4. CONCLUSIONS

The author had to admit that he failed in his initial attempt to trace the ‘law of natural movement’ and its subsequent economic feedback-loop in prehistoric settlements. However, with a more spatial based focus on social changes, the transition from Late Neolithic to Early Bronze Age was revealed as very important.

Fundamental social changes took place during End Neolithic. Migrating people from the east brought not only a new language, economic background and burial practices but also different ‘space-time-identities’ with them. They fusioned with local groups into Corded Ware Culture, a gradual process of acculturation and integration, which took several hundred years.

It cannot be excluded that the ‘law of natural movement’ may have developed in Late Neolithic. However, social changes overshadowed these spatial developments and “it was only on the advent of the Middle Bronze Age that cultural homogenization prevailed” (Kristiansen et al., 2017, p.338).

It is therefore likely that only from Middle Bronze Age onwards, socio-economic conditions with ‘individually acting producers and consumers’ in a more modern sense may be found. And it may be worth to analyse settlements of younger prehistoric periods with Space Syntax to trace the ‘law of natural movement’.
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#115

**SQUARES FOR CO-PRESENCE:**
The influence of urban form on the intensity and diversity of people co-present in 12 squares in Gothenburg

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**ABSTRACT**

Increasing residential segregation in cities gives public spaces a more important role in solidarity processes, bringing people together, supporting movement, co-presence and co-awareness. Local squares thus have the greatest significance providing an arena for social interplay as people become co-present. Earlier studies showed that high spatial integration plays an important role for the mix of locals and non-locals besides aspects relating to population density and land use.

The purpose of this paper is to reach a better understanding whether also more local properties that characterize a square influence co-presence. Further, more squares are added to represent a broader spectrum of neighbourhoods which will help us understand whether network integration is important in all types of neighbourhoods. Thirdly, this study will help to inform whether earlier findings by Legeby in Stockholm, Södertälje and Gothenburg can be confirmed which allows us to generalize these findings.

The amount of people co-present in squares and the share of non-local visitors are studied as two indicators (or aspects) of co-presence. The empirical data was collected through observation including snapshots and interviews. The number of people present in the public squares was noted and the interviews were used to measure the share of non-locals. The spatial analysis includes besides integration and betweenness, an analysis of density (both population and building density) and land uses accessible from the squares within various radii. Also, geometric characteristics such as size, shape and enclosure of the squares are included in the study.

The result shows different patterns of co-presence in the 12 studied squares, especially if we distinguish squares in the most central area of Gothenburg with squares located at a longer distance from the city centre. Some findings confirm earlier findings and allow us to generalize the findings as other findings seem not to be relevant in all cities. Further, pure geometric properties of squares do not show strong correlations with co-presence. We can thus conclude that the local design intervention of squares cannot promote co-presence very well without the support of urban structure.
KEYWORDS
Co-presence, public squares, urban form, space syntax, segregation in public space

1. INTRODUCTION
In many European cities the history of massive post-war housing expansion has left a legacy of notoriously segregated suburbs. The problems related to segregation and exclusion in Swedish cities are currently being discussed “to an extent not experienced before” (Legeby et al. 2015, p. 239). This is reflected in policy documents, municipal budgets and Comprehensive Development Plans. However, the situation is more complex with some suburbs suffering social problems much more than others (Vaughan 2005; Vaughan and Arbaci 2011).

Earlier studies have shown that public space has an important role to play as it can contribute in a positive way to solidarity processes, bringing people together, supporting movement, co-presence and co-awareness (Hanson 2000, Hanson & Zako, 2007; Legeby 2013; Netto, 2016). Public space is thus not only urban design elements important for enabling travel between destinations, but has an important role to play in providing a social arena for social interplay (Olsson 1998; Gothenburg Comprehensive plan 2009). The routines of day-to-day life result in social interaction and cultural exchange including the negotiations of views and norms (Giddens 1984; Zukin 1995) and can potentially contribute to overcoming social exclusion (Legeby 2013; Young 1996).

Architecture and urban design are seen in this debate as playing a central role for counteracting segregation, confirmed by formulations found in policy documents. But how do we know what kind of design principles lead to less segregation? Earlier studies highlight the importance of urban space which frames and supports everyday life in the city such as streets, squares and parks (Hanson & Hillier 1987; Vaughan, 2005; Hanson & Zako, 2007). With whom we potentially share the street and what resources are within easy access as we perform our day-to-day routines, it is argued, is of utmost importance for matters related to social exclusion (Vaughan 2015). Earlier studies of squares and centres in Stockholm and Södertälje (Sweden) show that specific configurational properties have great impact on the pattern of co-presence, both in terms of the amount of people present in public space and the inflow of non-locals (Legeby & Marcus, 2011; Legeby, 2013). The latter is argued to be as an indicator of diversity as people coming from different parts of the city and becoming co-present at the square/centre in question. More specifically, it is found that segregation of public space, a limited spatial reach and an uneven distribution of spatial centrality, appears not to favour exchange between neighbourhoods or access to urban resources across the city – findings that are highly critical for the urban segregation issue (Al Gatam 2012; Legeby, 2013, p. ii; Legeby et al., 2015).

A study in Gothenburg (Legeby et al., 2015) showed similar patterns, but no statistical analysis was carried out at that stage and the 9 squares studied were all located in neighbourhoods developed following modernistic planning ideals. Further, the variables studied did not include other variables that might be of importance such as the working population and access to different kinds of services (e.g. shops, restaurants, amenities), which was found to be important in Stockholm.

The central question for this paper is therefore not primarily whether spatial form influences co-presence, but merely how in more detail it does so and whether the findings in Stockholm, Södertälje and Gothenburg are similar so that we can start to generalize the findings to at least the Swedish context at large.

The study presented in this paper will therefore contribute to these earlier findings in two ways: firstly, by adding more squares representing a broader spectrum of neighbourhood types in Gothenburg (e.g. different typologies and different periods in history) and by adding all variables used in the earlier study in Stockholm, we can compare the results with the Stockholm case. Secondly, by adding some basic urban form characteristics of the squares themselves (e.g. size, enclosure and height of the surrounding buildings) that were not included in Stockholm and will give us insight whether the design of the square itself is of importance to co-presence or...
not. We find this important as it is a question that is highly relevant for architects and planners involved in the design of public space and the importance of such design features is argued by some to have a huge impact on the performance of, for instance, squares. As in the earlier studies (Legeby, 2013) two aspects of co-presence that are argued to influence the character of urban life and thus affects what kind of urban networks or solidarities may emerge are included. Firstly, ‘intensity’ in public space measured as the average amount of people present at the square on weekdays and secondly, ‘diversity’ or mix of people measured as the share of non-locals using the median metric distance to the home addresses of the people present at a specific square. Statistical analysis is then used to establish to what extent the inflow of non-locals corresponds to certain other attributes.

In the following section, the method will be explained including a discussion about the selection of squares, how the observation study was conducted, which spatial variables are included and how these are measured. In the section that follows, the results of the statistical analysis, relating the observation to the spatial analysis, are presented and in the last section the findings are discussed.

2. METHODS

2.1 SELECTING SQUARES

For the selection of squares, we used four criteria to ensure a good spread in spatial characteristics in terms of population density, centrality, size and enclosure. The accessible population was measured as the number of people living within a 500 metre walking distance from the square. Centrality was measured using betweenness1 at 2-kilometre radius which have the potential to support the active presence of people and the resultant urban economy (Remali et al. 2015). Enclosure was measured as the share of the perimeter of the square that was built upon. This will be explained in more detail in section 2.32. The values of each indicator are divided into three groups by natural breaks and the range of each group is shown in table 1. Putting the criteria of four indicators and squares into a selection matrix, we ensured to select different types of squares. As a result, 12 squares were selected (see figure 1). Besides three squares in the neighbourhoods Friskväderstorget in Norra Biskopsgården (1950s), Kyrkbytorget in Kyrkbyn (1950s) and Komettorget in Bergsjön (1960s) that were also included in an earlier study in Gothenburg (Legeby et al., 2015), 9 other squares were selected: Gustav Adolfs Torg (inner city, 17th century), Lilla Torget (inner city, 17th century), Masthuggstorget in Masthugget (mid-18th century), Kabbagestorget in Torpa (1940s), Doktor Fries Torg in Guldheden (1950s), Radiotorget in Järnbrott (1950s), Trätorget in Björkekärr (1950s), and Brotorget and Johan Sannes Torg in Sannegården (2000-).

<table>
<thead>
<tr>
<th>Accessible Population</th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;4463</td>
<td>4463-10090</td>
<td>≥10090</td>
</tr>
<tr>
<td>Betweenness</td>
<td>&lt;13808</td>
<td>13808-66617</td>
<td>≥66617</td>
</tr>
<tr>
<td>Size</td>
<td>&lt;1955m²</td>
<td>1995-4317m²</td>
<td>≥4317m²</td>
</tr>
<tr>
<td>Enclosure</td>
<td>&lt;0.37</td>
<td>0.37-0.56</td>
<td>≥0.56</td>
</tr>
</tbody>
</table>

Table 1 - The values of the four selecting indicators: accessible population, betweenness, size and enclosure

1 A measure of centrality developed by Freeman (1977). It analyses how often a segment is passed using the shortest paths between every point to all other points in the system within a certain radius.

2 This paper is the result of a Master Thesis conducted at Chalmers University of Technology by Kailun Sun and more details can be found in the report ‘Making Squares: a study of urban form and co-presence’. 
2.2 OBSERVATIONS
The empirical data contains two aspects of co-presence – ‘intensity’ and ‘diversity’ - and was collected through observation. Firstly, we counted people present at the square for a period of four minutes. These counts were repeated every hour for one day starting from 8:00 in the morning until 18:00 in the afternoon. These are then added up and divided by the total amount of counts during a day to arrive at the median momentary intensity.

The interviews were conducted to collect information about whom visits the square and why. Only one question of these interviews was used for this paper which is the question of the home address of the people visiting the square. The interviews were conducted on a weekday between 8:00 and 18:00, in between the counts that were done every half hour. Based on these home addresses we were able to measure the distance of the home address of the person visiting the square to the square in question. In this study ‘locals’ are defined as those living within 1000 meters of walking distance from the square. This distance is easy walkable (about 10-15 min) and has to do with how many of these neighborhoods are used, a kind of primary catchment area of the different neighbourhood centres and squares. Living further away increases the chance that residents will use another square/centre or another tram or bus stop. Besides, we used the median distance to these home addresses as a proxy for the mix of people co-present at the square where we don’t have to make the somehow arbitrary choice of the 1 kilometre threshold for being local or non-local. We used interviews to collect the information about the home addresses of the visitors. The interviews were conducted in between observing the intensity, meaning that we have data for diversity from people interviewed on weekdays from 8:00-18:00. The information about the home addresses was analysed and the distance from the square to these addresses calculated. Some addresses are located really far away from the squares and these influence the average levels. We therefore used the median value which is not skewed so much by extremely large or small values, and so may give a better idea of a ‘typical’ value. This is also a way to deal with addresses located in positions not covered by the axial map.
2.3 SPATIAL ANALYSIS

The spatial analysis of the squares and its surroundings will be carried out in a way that acknowledges the city as an urban system that makes sense for where people are and how they move around. We distinguish four levels of spatial analysis: patterns of centrality using network analysis; patterns of population density including both residential population and working population; patterns of land use where we analysed the proximity to different kind of services; geometric characteristics of space from the scale of the local square to the scale of the neighbourhood.

The centrality analysis includes two network analyses of centrality, betweenness and integration from local to global scale. Analysing the spatial integration of a system defines how accessible each space (or its representation: the axial line) is from all other spaces (or axial lines) in the system (Hillier & Hanson 1984, Hillier 1996). In a way, it is a method used for describing how far away or how ‘deep’ each space is in the system, in relation to all others. Another way of measuring centrality is to analyse how many distance-minimising paths there are between every pair of segments. This is a way to identify important links connecting the spatial system is called betweenness.

Further, a series of attraction analysis were conducted including accessible population (residential and working population), accessible built density (measured as volume per area, m³/m²), network density (measured as street length per area, m/m²), accessible services (amount of public amenities and food related services including cafes, groceries and restaurants) and public transportation (amount of stops resp. amount of different lines). All were conducted at three scales of walking distance, that is, 500m, 1km and 2km, except for public transport (number of tram/bus lines but not number of stops) which was only calculated for a 500m radius. These analyses were done counting the amount of, for instance, restaurants, accessible within a distance of 500m using the street network. This means that the outcome depends both on the amount of restaurants (or any other attraction) and on the street layout. A grid-like pattern will give rather equal access in all directions and a tree-like street pattern tends to reduce the area one reaches, its spatial reach (Legeby, 2013) (see figure 2). This area one can reach (i.e. spatial reach) is a variable in the statistical analysis as well as it is used to calculate density in for instance accessible population density, accessible built density and accessible network density (Berghauser Pont & Marcus, 2014; Berghauser Pont & Haupt, 2010; Peponis et al., 2008).

![Figure 2 - Spatial reach of two squares where the area is drawn using a convex hull based on the end points of the street segments reached within 500m walking distance](image-url)

For public amenities the following land uses are included: libraries, sport facilities, leisure space, etc; for food services the following land uses are included: cafés, restaurants and groceries.
Thirdly, three more local urban form analyses were conducted including the size of the square, the enclosure of the square and the average height of the buildings that enclose the square. The size of the square was measured by drawing boundaries for each square, according to Gothenburg aerial map, excluding the adjacent streets. For enclosure, the polygon of the square was used in the measure of enclosure (see figure 3) where the length of the boundary that touched buildings is divided by the total length of the boundary. In cases of a setback, where the buildings do not directly front the square, but have for instance a street dividing them from the square, an offset was used; the offset is set until it cuts through main buildings. In this case, the percentage of the offset boundary cutting through buildings was counted. To capture the vertical dimension of the physical space at the square, the average building height was measured along the boundary of the square or the offset as explained earlier, weighted by the length of the shared perimeter.4

2.4 DATA BASE AND MODEL
The network model used in the study is the hand-drawn axial map (and the segment map is derived from it). The axial map represents the pedestrian network, thus motorways and ferries are excluded. This is the same map as was used in the earlier study (Legeby et al., 2015). The geographical data as well as observation data of three squares, Friskväderstorget, Kyrkbytorget and Kommettorget, also come from the work of Legeby et al. (ibid). New observations were added in 2016. Most of data is on address level except for the population data, which is aggregated into cells of 100x100m. Analysis of building densities use data of building heights that were extracted from a laser dataset containing a Digital elevation model (DEM) and Digital surface model (DSM).5 Then, DEM was subtracted from DSM to make a new surface model called Digital height model (DHM) which contains the real height values of the features on the ground. In the final step, building footprints were added and the average height value of each footprint was considered as the height of each buildings.6

2.5 STATISTICAL ANALYSIS
In the statistical analysis, we looked for correspondence between the observations (intensity and diversity of people co-present) and the spatial analysis of the 12 squares. Sometimes we divided the data in two groups; on the one hand squares in the city centre (Lilla Torget and Gustav Adolfs Torg) and on the other hand all other squares. We did this because the squares in the centre often stood out from the other squares. They had, in comparison to other squares, an extreme high diversity and intensity of co-presentation as can be seen in figure 4. One can almost say that they represent another category, different from the other 10 squares which we from now on will refer to as non-CBD squares. This group should be studied separately from the squares in the centre (from now on referred to as CBD-squares) as some details of the trends in these non-central areas will be hidden because of the dominance of the CBD squares when looking at all of them at the same time. When discussing results, we will both discuss them for all squares and for the non-CBD squares separately.7

Figure 3 - Local urban form analysis

4 GIS software MapInfo Pro. 15.0 and the Place Syntax Tool 2.10.7 are used for the spatial analysis.
5 Lantmäteriet (https://www.lantmateriet.se/); the average resolution used for the preparation is 2m.
6 See Berghausen Pont et al., 2017 for extended description.
7 In statistical analysis SPSS (IBM SPSS Statistics 22) is used.
3. RESULTS

In the following section we will present the results of the observations of people counts (to measure momentary intensity) and the interviews (to measure the share of non-locals), the spatial analysis and the relation between these two. The results of the spatial analysis will be shown starting with the configurative properties, followed by the analysis of accessible population and amenities and lastly the very local geometric properties of the squares. In section 3.3 the relation between the spatial analysis and the amount of people being present at the squares (intensity) is discussed and in section 3.4 with the share of non-locals (indicating diversity).

3.1 OBSERVATIONS

Gustav Adolfs Torg had the most visitors among all squares and Johan Sannes Torg got the least (see table 2). Further, the charts (figure 4) show very clear that two squares have many more visitors and a higher share of non-locals than all the other squares. These are the two central squares we referred to earlier as CBD squares: Gustav Adolfs Torg and Lilla Torget. Gustav Adolfs Torg had a median of 57 people visiting the square on our 4-minute counts. The average for all squares was 19. The share of non-locals is 93% which is very high in comparison to the average of 50%. We discussed these two groups of squares, CBD and non-CBD, already in section 2.4 where we proposed to look at the results of the statistical analysis for all squares and when excluding these two, what we called, CBD-squares.

Table 2 - Observations: intensity and diversity

<table>
<thead>
<tr>
<th>Square</th>
<th>Intensity</th>
<th>Diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Median of people co-present</td>
<td>Median Distance (m)</td>
</tr>
<tr>
<td>Brextorget</td>
<td>25</td>
<td>1 343</td>
</tr>
<tr>
<td>Doctor Fries Torg</td>
<td>35</td>
<td>864</td>
</tr>
<tr>
<td>Fridhuvudtorget</td>
<td>17</td>
<td>531</td>
</tr>
<tr>
<td>Gustav Adolfs Torg</td>
<td>57</td>
<td>4 973</td>
</tr>
<tr>
<td>Johan Sannes Torg</td>
<td>2</td>
<td>280</td>
</tr>
<tr>
<td>Kaggelidtorget</td>
<td>16</td>
<td>630</td>
</tr>
<tr>
<td>Kornetorget</td>
<td>18</td>
<td>345</td>
</tr>
<tr>
<td>Kyrkhojtorget</td>
<td>4</td>
<td>627</td>
</tr>
<tr>
<td>Lilla Torget</td>
<td>31</td>
<td>4 950</td>
</tr>
<tr>
<td>Masthuggstorget</td>
<td>18</td>
<td>1 064</td>
</tr>
<tr>
<td>Radstorget</td>
<td>4</td>
<td>725</td>
</tr>
<tr>
<td>Trastorget</td>
<td>21</td>
<td>742</td>
</tr>
</tbody>
</table>

Figure 4 - Charts with results of intensity and diversity

The overview of all correlation results can be found in appendix 2.
Besides these values, it is also of interest to consult the maps where the locations of the home addresses are plotted and one can see how these are distributed. Figure 5 shows that for some squares such as Gustav Adolfs Torg, the red dots are spread out over large parts of the city. At Kaggeledstorget, on the other hand, most visitors live in the same or in adjacent neighbourhoods; the dots on the map are more concentrated. In other words, the latter is mainly used by locals and the average distance from home to square is short. If we now again look at the numbers (table 1), we see that 93% of the visitors at Gustav Adolfs Torg are not local (i.e. they live further than 1 km away from the square); Kaggeledstorget on the other hand, is more local, with only 45% non-locals. The lowest share of non-locals is found in Johan Sannes Torg, but here we only had very few people visiting the square which might have affected this outcome. In addition, it is possible to see that the river Göta älv seems to have a barrier effect at many squares as most visitors live at the same side of the river where the square is located. The two inner city squares being the exceptions.

Figure 5a - Maps with the distribution of home addresses (6 squares)
Figure 5b - Maps with the distribution of home addresses (6 squares)

3.2 SPATIAL ANALYSIS

3.2.1 CONFIGURATIVE PROPERTIES

Integration and betweenness are two measures that describe the configurative properties as well as centrality in cities, properties that have proven to be of great importance for different kinds of processes taking place in cities, not least social processes that are at the core of this paper. The 12 squares studied are located in neighbourhoods with different centralities. The neighbourhoods in the north, for instance Bergsjön where Komettorget is located, are less integrated compared to the neighbourhoods in the south of the Göta River (see figure 6a). When looking at betweenness, we can see that the neighbourhoods in the north are more fragmented with ‘islands’ of higher betweenness values instead of a continuous path as we see in the south (figure 6b).
3.2.2 POPULATION DENSITIES

The areas surrounding the squares cover low, medium and high-density areas, both in terms of accessible working and residential population. If we look at the population accessible within a radius of 500m walking distance, most squares in the modernist neighbourhoods have a rather low working population. The two CBD squares are located in neighbourhoods with a very high working population, but a low residential density (see figure 7a). The highest working population within 500m walking distance is found around Gustav Adolfs Torg with almost 25,000 persons and the least around Johan Sannes Torg with only 150 jobs. Accessible residential populations spreads from 1,379 to 5,144 persons within the same radius of 500m.
3.2.3 PROXIMITY TO SERVICES
CBD squares have access to a much higher amounts of services than the other squares. The non-CBD squares with low numbers of accessible service usually have public transport, public amenities and food service, but only few of each; they have a grocery, a café/bakery, a bus/tram stop, some public amenity, etc., and offer the basic setup for daily life. The biggest variation in the amount of accessible services between squares is found when analysing accessible food services; the difference can be more than 10-fold.

![Accessible public amenities and accessible food service](image.png)

3.2.4 GEOMETRIC CHARACTERISTICS OF THE SQUARES AND ITS SURROUNDINGS
The built density, measured as volume density, is highly correlated with total population density, but does not distinguish between working and residential population as we will soon see, is of importance. The difference in network density relates directly to the area of reach. Both are higher in the more central areas than in the areas with a more tree-like setup dominant in the suburbs.

3.3 RELATION BETWEEN THE SPATIAL PROPERTIES AND INTENSITY

3.3.1 CONFIGURATIVE PROPERTIES
The strongest correlation between integration and the amount of people is found at the R4, 6 and 10 and less on both very local (R2) and global scales (R14 and higher). By taking out the CBD-squares from the analysis, however, no correlation is found. Integration, it seems, is mostly an indicator for the centrality of the squares and explains the difference between the centre and suburbs, but it does not explain the differences between the squares located outside of the city centre (i.e. the non-CBD squares). The correlation between the amount of people and betweenness is found significant at radii 1km and 2km when all squares are included. Here, the correlation is stronger ($r = 0.81$) when the CBD-squares are excluded, at least at radius 1km. In other words, betweenness shows a strong relation with the amount of people both in the non-central areas and when all squares are included; betweenness thus seems to be important for squares in order to be used intensely.
3.3.2 POPULATION DENSITIES

A strong correlation is found between population density and the amount of visitors counted at the 12 squares. Noticeably, it is the working population that seems to play an important role, as we did not find correlations when looking at only the residential population. Highest correlations are found at the most local scale, radius 500m ($r = 0.86$). This confirms earlier findings by Legeby (2013) in Stockholm and Södertälje (2010). However, by taking out the two CBD-squares, none of the variables are significant anymore. The huge variation in working population in the city with very high numbers in the centre and very low in the rest of the city can be the reason for these results.

3.3.3 PROXIMITY TO SERVICES

The correlations with the amount of service found in proximity of the squares are strong when all squares are included. Without CBD-squares, however, no significant correlations are found. This corresponds to the findings we discussed earlier when looking at population density. The presence of many services and high population density seem important for the amount of people using the squares, but differences in the amount of people counted at the non-CBD squares cannot be explained by population density nor by the amount of services found in the vicinity of these squares.

3.3.4 GEOMETRIC CHARACTERISTICS OF THE SQUARES AND ITS SURROUNDINGS

A higher spatial reach, higher built density and network density on a local scale (radius 500m) is important for the amount of people counted when all squares are included. However, again, as we discussed so many times earlier, when excluding the CBD-squares, no correlations are found. When it comes to the size of squares and enclosure, this is not important at all; not when all squares are included and not when we reduce it to the 10 non-CBD squares.

3.4 RELATION BETWEEN THE SPATIAL PROPERTIES AND DIVERSITY

3.4.1 CONFIGURATIVE PROPERTIES

Strong correlations are found between integration and diversity for all squares throughout all scales, measured both as share of non-locals and measured as median distance to home address. By taking out the CBD-squares, no correlations are found. For betweenness we find correlations for radius 1km and 2km, but most significant results are found for 2km using the share of non-locals. This result is even found when only looking at the 10 non-CBD squares. In other words, the connections between adjacent neighbourhoods is important in the design of squares if the goal is to have a higher share of non-locals present at these squares. Further, as we discussed in section 3.3 also for the amount of people, betweenness showed a high correlation. Betweenness at 1km and 2km scale thus seem to play an important role in the discussion on co-presence. We will return to this shortly.

3.4.2 POPULATION DENSITIES

Population density shows very high correlations with the share of non-locals when all squares are included, and again, as we have seen earlier, the working population is giving higher correlations. The results without the CBD-squares show only correlations at the 2km radius and surprisingly, the residential populations gives the highest correlation ($r = 0.65$) when correlating with the share of non-locals. Working population correlates but with a low level of significance (p-value at the 0.1 level). When we, instead of share of non-locals, correlate the median distance to home addresses with population density, the working population gives the highest correlation ($r = 0.62$), but again with a low p-value. We might thus conclude that a higher share of non-locals is related to population density in general, but that working population has an important role to play and only increasing the residential population is not enough. In other words, we find here an indication for the importance of mixed neighbourhoods.
3.4.3 PROXIMITY TO SERVICES

The same trends are found when the share of non-locals is correlated with the proximity and access to public amenities, public transport and food services; strong correlations when all squares are included and none when the CBD-squares are excluded; except for public transport. The amount of public transport stops shows a high correlation when using the share of non-locals ($r = 0.83$) and moderate when using the median distance to home addresses ($r = 0.63$). The amount of cafés, restaurants and grocery stores (i.e. food services) shows a correlation ($r = 0.56$), but with a low significance (only at the 0.10 level) and any conclusion would therefore be highly suggestive. That public transport might play an important role for the share of non-locals is not so surprising and can be related to betweenness where in both cases infrastructure allows for people to visit the area. The presence of public transport allows people from far away to visit the squares and is thus an effective ‘door’ to enter the square from neighbourhoods elsewhere in the city.

3.4.4 GEOMETRIC CHARACTERISTICS OF THE SQUARES AND ITS SURROUNDINGS

Spatial reach is important at radius 500m and a general high volume and network density seems important at all scales. When excluding CBD squares, only accessible volume density at 2km walking distance shows a correlation, but weak and with low significance. However, this confirms our findings for the population densities discussed earlier. When it comes to the size of squares and enclosure, no correlations are found. We can thus conclude that for the share of non-locals, the geometric characteristics do not play a role of importance. This does, however, not say that these characteristics are unimportant. They might be highly relevant for the experience when visiting the square, but this is not the question this paper tries to answer.

4. DISCUSSION AND CONCLUSIONS

From the results of the statistical analysis, we see clearly different patterns of co-presence in the 12 studied squares in Gothenburg. Firstly, the clear difference between the CBD and the non-CBD squares. This is by no means a surprising finding, but for practice and not least for politicians working with urban planning and design, it can be good to be aware of the fact that what you have in the most central areas cannot easily be copied to peripheral areas with less centrality and less density. Adding only density, we have seen, will not do the job. It is the combination of both, that makes central areas and squares crowded. However, when it comes to the amount of non-locals, we found a strong correlation with betweenness at 2km radius. This means that squares that are not so intensely used, still can have a diversity of people visiting them, that is, both local and non-local visitors. In design terms, this means that we need to design the relations between neighbourhoods so that people pass a square in neighbourhood X when moving from neighbourhood Y, via X to Z. This is an important finding as it can in a positive way contribute to solidarity processes, bringing people together (Hanson 2000; Hanson & Zako 2007; Legeby 2013), social interaction and cultural exchange including the negotiations of views and norms (Giddens 1984; Zukin 1995) and can potentially contribute to overcoming social exclusion (Legeby 2013; Young 1996). These findings correspond to the conclusions from the earlier study in Stockholm, Södertälje and Gothenburg allowing us to generalize these findings, at least for Swedish cities.

For all other variables, the huge variation between CBD and non-CBD squares are dominating the more nuanced variations between the non-CBD squares. CBD squares have a much higher centrality (in terms of integration), much higher number of people working, higher network densities, many more amenities, and all this overshadows so to speak the minor variations of these variables in the non-CBD squares. This is the reason these squares were analysed separately.

When analysing the non-CBD squares, only few variables seem to be of importance. For the intensity of people, it is only betweenness at a radius of 1km that correlates. For diversity we found only three important variables (that correlate): betweenness (radius 2km), population density (within walking distance 2km) and the number of public transport stops (walking
Thus we can try to conclude that for squares located in less central areas (areas with relative low integration values), betweenness is the key to activate squares. In other words, the importance of spatial conditions is more clearly seen here than in the city, and in order to get a less segregated square, we need to put more emphasis on the configurational design of the square, or, in other words, we need to better connect neighbourhoods to promote through movement. Adding more shops and attractions would probably not change so much and we could even go so far as to say that when spatial interventions are successful, it becomes more probable that new shops will occur as a result of an increase in people visiting the square.

A surprising result is that the amount of accessible jobs (i.e. working population) that was shown to be important in Stockholm and Södertälje when correlated to the share of non-locals does not show similar strong results in Gothenburg. The correlation found in Gothenburg is modest, but with a rather low level of significance. Accessible residential population, though, shows a stronger correlation. This is something that should be looked in more closely in the future.

The pure geometric properties and especially the very local ones such as size of the squares and enclosure did not correlate at all with intensity nor diversity. We can thus conclude that without the support of urban structure, the design of the squares itself cannot drive a more diverse inflow neither have impact on the amount of people present. Instead, we should improve the configurative properties and sometimes dare to invest outside of the square when we want to create a square that can attract larger numbers of non-locals to contribute to solidarity processes and potentially contribute to overcoming social exclusion. This does not imply that the design of the square itself is not important, but this cannot make them more crowded nor more diverse.

The conclusions presented here are based on the empirical data that were collected on weekdays, from 8 o’clock to 18 o’clock. During this time of day, most people show up in public space when they commute to work, have lunch, have coffee break and go home from work. However, the pattern of co-presence on weekends, if we would have the empirical data on weekends, might change the results considering the different purpose and destination of journeys and the flexible time people have to go out in public space during weekends.

Further, it should be stated again that this study is based on only 12 squares, or 10 squares when excluded the two CBD-squares. This is a rather small amount of samples for the correlation analysis. In other words, the reliability of the result relies on the selection of few squares. For the results that confirm earlier findings in Stockholm, Södertälje and Gothenburg, we can be confident that the results are robust. However, those that show discrepancies need to be interpreted cautiously.
REFERENCES


Young, Iris M. (1996), "City Life and Difference".


APPENDIX 1

SPATIAL ANALYSIS

<table>
<thead>
<tr>
<th>No.</th>
<th>Square Name</th>
<th>Intensity</th>
<th>Diversity</th>
<th>Integration</th>
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<tr>
<td></td>
<td></td>
<td>Median</td>
<td>Median</td>
<td>Share non-locals</td>
</tr>
<tr>
<td>1</td>
<td>Brotorget</td>
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<td>3143</td>
<td>57%</td>
</tr>
<tr>
<td>2</td>
<td>Doktor Fries Torg</td>
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<td>864</td>
<td>68%</td>
</tr>
<tr>
<td>3</td>
<td>Friskvåldstorget</td>
<td>17</td>
<td>534</td>
<td>28%</td>
</tr>
<tr>
<td>4</td>
<td>Gustav Adolfs Torg</td>
<td>17</td>
<td>4973</td>
<td>93%</td>
</tr>
<tr>
<td>5</td>
<td>Johan Sandes Torg</td>
<td>2</td>
<td>185</td>
<td>18%</td>
</tr>
<tr>
<td>6</td>
<td>Kaggelevdstorget</td>
<td>10</td>
<td>634</td>
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</tr>
<tr>
<td>7</td>
<td>Konnatarget</td>
<td>18</td>
<td>346</td>
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</tr>
<tr>
<td>8</td>
<td>Kyngbystorget</td>
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<td>690</td>
<td>39%</td>
</tr>
<tr>
<td>9</td>
<td>Lilla torget</td>
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<td>91%</td>
</tr>
<tr>
<td>10</td>
<td>Måtleppstorget</td>
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</tr>
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<td>11</td>
<td>Radiatorget</td>
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<td>12</td>
<td>Tidstorget</td>
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<td>748</td>
<td>34%</td>
</tr>
</tbody>
</table>

APPENDIX 2

SQUARING FOR CO-PRESENCE:
The influence of urban form on the intensity and diversity of people co-present in 12 squares in Gothenburg

<table>
<thead>
<tr>
<th>No.</th>
<th>Betweenness</th>
<th>Local urban form</th>
<th>Are of square(m²)</th>
<th>Enclosure</th>
<th>Building Height(m)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1,531</td>
<td>21,414</td>
<td>50,146</td>
<td>19,016</td>
<td>18,651</td>
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<td>61,205</td>
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<td>125,973</td>
<td>62,495</td>
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<td>4</td>
<td>2,716</td>
<td>21,222</td>
<td>124,049</td>
<td>52,725</td>
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</tr>
<tr>
<td>5</td>
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<td>20,261</td>
<td>124,672</td>
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<tr>
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</tr>
<tr>
<td>7</td>
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<td>20,049</td>
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### SQUARES FOR CO-PRESENCE:
The influence of urban form on the intensity and diversity of people co-present in 12 squares in Gothenburg

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## APPENDIX 2

### CORRELATIONS WITH 12 SQUARES (INCLUDING CBD SQUARES)

#### Integration

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#### Correlations with 12 Squares (Including CBD Squares)

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**. Correlation is significant at the 0.05 level (2-tailed).**

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**. Correlation is significant at the 0.05 level (2-tailed).**

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**. Correlation is significant at the 0.01 level (2-tailed).**

**. Correlation is significant at the 0.05 level (2-tailed).**
### CORRELATIONS WITH 10 SQUARES (EXCLUDING CBD SQUARES)

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<tr>
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<td>R4</td>
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<tr>
<td>Intensity_median</td>
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<tr>
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<td>0.05</td>
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</table>

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
# SQUARES FOR CO-PRESENCE:
The influence of urban form on the intensity and diversity of people co-present in 12 squares in Gothenburg

## Correlations

<table>
<thead>
<tr>
<th>Intensity</th>
<th>Residential PN</th>
<th>Residential SN</th>
<th>Residential WN</th>
<th>Work PN</th>
<th>Work SN</th>
<th>Work WN</th>
<th>Total PN</th>
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<td>0.362</td>
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<td>0.283</td>
<td>0.440</td>
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<table>
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<th>0.373</th>
<th>0.451</th>
<th>0.519</th>
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<td>0.166</td>
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*Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

## Correlations

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<tr>
<th>Intensity</th>
<th>Network density</th>
<th>Public transportation</th>
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<th>0.494</th>
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<tbody>
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<table>
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<tbody>
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<td>Sig. (2-tailed)</td>
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<td>0.344</td>
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</table>

*Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).
WEAVING A BRIDGE ACROSS THE ATLANTIC:
Points of Approximation in the Spatial Structure and Urban Character of Natal (Brazil) and Dakar (Senegal)

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ABSTRACT
The research that anchored the study to be presented here forwards a comparative analysis of two cities sited in opposite continents across the Atlantic – Natal in Brazil, and Dakar in Senegal – aiming to draw attention to similarities or “points of approximation” concerning the nature of their foundation, their urban development and the relations they have sustained with their territories. This paper addresses specifically the spatial imprint, which resulted from, and upheld, the establishment and expansion of the two cities, as concerns topological accessibility and the formation of centralities, in diachronic and comparative perspectives. Natal and Dakar were both founded within the context of the European mercantile expansion, serving as spearhead settlements for conquering, consolidating and controlling territories under colonial rule as well as giving support to commercial routes. Their privileged positions, east and west of the Atlantic, also rendered them key roles in overseas routes connecting Europe, Africa and America, particularly in the so-called “Golden Age of Aviation” (1920s and 1930s), and in World War II, when they became strategic points in the international geopolitical scene and sites of important military bases. Natal and Dakar were examined by means of space syntax procedures (axial and segment analysis) to represent successive stages of their urban expansion along the 20th century and enable comparison of morphological features amongst development phases for each city and between them, in the light of the literature about their urban character and transformation during the studied time-span. The diachronic configuration analysis revealed expansion axes that anticipate future occupation, exposing how accessibility properties shifted over time and centralities were created, thus showing the physical imprint of actions (or their absence) that structured the urban milieu and defined the social distribution of inhabitants in both cities. Besides adding to the understanding of our common historical legacy, this brief insight shows that despite the radical sociocultural differences concerning the two cities, the physical attributes of their natural sites coupled to the roles they played in the world political
scene, and to the social logic of space in national and global capitalism, have left formal imprints that indicate similar processes of accessibility formation and transformation throughout time and how these accessibility patterns have been unequally reached by socially distinct people.

KEYWORDS
Space configuration, Urban expansion, Points of approximation, Natal, Dakar

1. KNITTING POINTS OF APPROXIMATION ACROSS THE ATLANTIC

The research on which this study is based aimed to explore similarities between two cities sited opposite one another across the Atlantic – Natal (Brazil) and Dakar (Senegal) – concerning their physical relations with their territories and their urban development since their foundation. It was developed along ten years (2006 to 2015), involved fieldwork in both cities and rooted papers that addressed findings from consecutive stages of the research progress, now being gathered into a forthcoming book (Teixeira, 2017). These findings outline “points of approximation” linking the history of the two cities that are ingrained in their physical milieu. Based on a gargantuan effort of textual and iconographical data collection, the analysis about how the two cities related to their territories as they expanded in time, carried on by Rubenilson Teixeira, the researcher who conceived and coordinated the project, was complemented by space syntax analysis for which we were invited to collaborate. The study herein presented stems from such collaboration, dealing with topomorphic relations of Natal and Dakar in diachronic and comparative perspective. It specifically addresses the spatial imprint, which resulted from, and upheld, the establishment and expansion of the two cities, as concerns topological accessibility, the formation of centralities, and the distribution of functions.

A crucial obstacle to the study was the meagre array of detailed cartographic records (displaying the complete street grid) for both towns, more so for Dakar, despite the efforts of the historiography research team to gather maps from digital and printed sources. The problem was partly overcome by the acquisition of a few precious items, courtesy of overseas researchers, or during scrutiny in the archives of academic foundations in Dakar, although the short time available for fieldwork, within the limits of the research project, impeded a thorough search. At length, an array of maps from various sources, epochs, information content and accuracy levels was examined and helped to clarify aspects concerning the morphological nature of the physical artefact of Dakar in combination with the literature. Of these, the ones we considered that represented more clearly the street grid at consecutive time intervals were chosen to anchor the configuration analysis, which progressed independently from the historiographical review, with researchers meeting on occasion to compare findings regarding the physical objects that comprise both cities, especially Dakar since that of Natal had been an item of morphological investigation for decades. Configuration findings were however refined in recent times for both cities through the application of later space analysis tools, which although not substantially altering previous results, contributed to further their comprehension, especially regarding the formation and co-existence of distinct centralities.

Natal and Dakar were examined by means of axial and segment analysis to represent successive stages of their urban expansion along the 20th century with the aim of inquiring on the possible interplay of morphological features and the character and function of certain places, to enable comparison among development phases for each city and between them, in the light of the literature about their urban character and transformation during the studied time. Despite the representation difficulties and the distinct investigation paths trod by the researchers – that of understanding urban form and function from the historiography and that of understanding social history from spatial relations – the two sets of findings mostly confirmed and reinforced one another.

Various “points of approximation” were disclosed throughout the investigation of historiographical and iconographical records (Teixeira, 2017, passim). Of these some that have particularly strong physical expressions and may be considered as common imprints bridging
the two cities are: (1) geographic limits and natural barriers orientate their expansion; (2) long axes, formerly roads connecting isolated settlements, conduct the expansion by linking the old town centre to strategic locations (of which air fields deserve distinction), and generating a new powerful accessibility network that unites and sets apart, also functioning as border lines to define social clustering within the territory; (3) expansion axes distribute accessibility unequally along the territory creating routes that develop in certain directions, which will become privileged exclusory urban areas; and (4) occupation patches sprout from tracts of land interspersed amongst main axes giving rise to new centralities that may respond to the needs of socially diverse residents.

2. NATAL AND DAKAR: TWO CITIES SEPARATED AND UNITED BY AN OCEAN

Natal and Dakar were both founded within the context of the European mercantile expansion, serving as spearhead settlements for conquering, consolidating and controlling territories under colonial rule as well as giving support to commercial routes that bonded colonies to their respective metropoles. Their privileged positions, east and west of the Atlantic, also rendered them key roles in overseas routes connecting Europe, Africa and America, particularly in the so-called “Golden Age of Aviation” (1920s and 1930s), and in World War II, when they became strategic points in the international geopolitical scene and sites of important military bases.

Natal was founded in 1599, by royal decree, the year following that of the construction of the Reis Magos fortress, one of many erected along the South American coastline as part of a defence strategy to protect Portuguese / Spanish domains (the two crowns were united from 1580 to 1640) in South America. The settlement, said to have been designated as “town” from start, though being nothing more than a poor hamlet, was established in the hope of providing some support to the fortress, constantly ransacked by Indians and smugglers (notably French invaders). Surrounded by the wide estuary of the river Potengi (the “great river” that gave name to the state of Rio Grande do Norte, of which Natal is the capital city), the ocean and a desert of sand dunes stretching out east and south, the town suffered severely during the Dutch invasion (1630-1654) and remained isolated and poor for nearly three centuries so that in 1899 the estimated population was little more than 16,000 souls.

The 20th century brought trade growth, immigrants, the dawn of aviation and hordes of transitory people following the installation of military bases during World War II. New neighbourhoods (Cidade Nova, Alecrim and Rocas) enlarged the 19th century urban occupation formed by Cidade Alta (or “high town” the foundation site on the hill overlooking the river) and Ribeira (the “riverside” surrounding the harbour). The new neighbourhoods signal the socioeconomic logic of territorial occupation that would shape Natal along the century. Cidade Nova, the first planned residential neighbourhood was conceived under precepts loosely guided by garden city principles with broad tree-lined avenues flanked by detached houses with front gardens; bordering country land that belonged to prominent families was turned into valuable urban ground, which would, from then on, concentrate public and attract private investment, thus becoming a high-status location to this day. Rocas, on the contrary, was gradually occupied by poor migrants, mostly peasants driven out of their land by the severe droughts that made surviving impossible in the sertão hinterland. Another frequent destiny for newcomers, the Alecrim – the first arrival point as one approached Natal from the hinterland by the neighbour town of Macaíba – developed into a residential and commercial location, later to become the most densely populated part of town, mainly inhabited by middling social sectors.

In the early 20th century Natal, therefore, comprised Cidade Alta, Ribeira, Alecrim, Cidade Nova and Rocas. In the foundation site of Cidade Alta, churches and public buildings signalled its religious and administrative functions and the variety of house forms indicated a socially mixed residential ensemble; Ribeira, site of the harbour, the railway termini and later, of a hydroplane base was rapidly being consolidated as the new active centre whereas Alecrim developed into an alternative centrality especially as concerned the commerce of farming goods. Cidade Nova

1 “Upper town” and “lower town” settlement comprise a mode of occupation extensively adopted by Portuguese founders. Salvador, in Bahia, and Olinda, in Pernambuco, are two notable such cases in Brazil, as is Lisbon itself.
and Rocas were sparsely occupied as residential neighbourhoods for the richer and the poorer, respectively.

Besides the hydroplanes base near the harbour, land airfields were built in the vicinities of the town in the late 1920s, initially by French companies in a location known by the Indian toponym of Parnamirim. A direct navigation route between Natal and Dakar was started at the time to aid the newly born transatlantic aviation link.

Parnamirim was also the location chosen by the American forces to build what was considered as the most important military base outside the United States territory at wartime. A second base, controlled by the Brazilian military (namely to keep up some appearances of authority) was also established there. The South Atlantic route, departing from Miami, Florida, with stops in the Caribbean, Brazil and Africa, mostly through a Natal-Dakar direct link, gains importance after the unsuccessful attempt from British and French forces to take control of Dakar in 1940. From September 1941 on and until the end of the war the American base of Parnamirim is said to have been crucial as part of the attack strategy for the allies. Historians (i.e. Hendricks, 1992:43) mention, for instance, 1675 combat planes having passed through Natal in March 1944.

By the end of the war, other neighbourhoods were being developed from settlements – mostly poor – along the coast (Praia do Meio and Aerea Preta) and the river (Quintas), as well as in the vacant grounds (Lagoa Seca) interspersed amongst roads running to other towns and hamlets. The south and east parts of Natal spread from the old town centres of Cidade Alta and Ribeira, through the first planned residential area of Cidade Nova – current neighbourhoods of Petropolis and (part of) Tirol – branching into a series of axes that link Natal’s municipal perimeter to those of Parnamirim, Macaiba and beyond.

The north part of town across the river – the Zona Norte (North Zone) – remained as a small settlement alongside the road to hinterland and coastal regions until the 1970s when it was developed as a residential area, predominantly to accommodate low income housing estates. It is now undergoing a process of centrality generation brought about by the expansion and conurbation of municipalities and settlements within the great Natal and strengthened by the proximity to the new airport located in the neighbouring town of São Gonçalo do Amarante. Natal’s population grew from 103,000 inhabitants in 1955 to approximately 800,000 in 2005, considering the municipality boundaries and to 1.3 million people (2010 census) considering the nine municipalities that comprise its metropolitan area, spreading both sides of the Potengi and along the coastlines, north and south of the river estuary.

In the 19th century an estimated population of 12 thousand Lebou people lived in the settlement denominated Dakar. In 1857, the town of Dakar was planned and established on a high land or Plateau. In the early 20th century – according to the studied map dated 1908 (SECK, 1970: 124-125), the urban occupation had nearly doubled having stretched in all directions but mainly towards south (Cape Manuel) and west.

The great epidemic of 1914-15 led to the construction of the Medina – a regular grid of orthogonal streets built over a swampy terrain – and consequent separation of the population in two urban settlements: the Plateau for the French, the Medina for natives, well set apart by a non aedificandi area. Thus, the construction of the Medina turned out to be an obstacle to the town growth as the neighbourhood (and its cordon sanitaire) isolated the old town centre from the north of the Peninsula. The imposing barrier of the Medina was eventually overcome as the land where construction was formerly prohibited appears in a 1934 map comprising an allotment showing signs of occupation though sparse, in the area where Rebeus now stands. By that time, investments had turned the harbour into one of the most important French naval bases in the Atlantic and a key support point for the action of the allied forces – naval and air – from 1941 on.

As had occurred in Natal, there were two aviation fields in Dakar before wartime: the formerly military aerodrome of Quakam, out of town, and a maritime hydroplane base (in Bel-Air), from where planes arrived and departed to overseas routes across the Atlantic. Besides these, a third aviation port was built in 1941 as part of the complex pertaining to the American military base,
initially in Rufisque, later transferred to Yoff. To a considerable measure therefore, aviation shaped the territory and sat the pace for urban development along the 20th century Dakar.

By the end of World War II the city had expanded from the extreme south of Cabo Manuel towards northwest and northeast, in the directions of Almadies, N’Gor, Yoff and Camberène. However, these areas were still not part of the urban grid that had spread throughout the south half of the Peninsula so that the former route des puits, or “wells way”, present day Bulevar du Presidente Habib Bourguiba, located half way up the land (figure 9), marked the town limits until the 1950s. Scattered settlements lay to the north and northwest of that road, some of which surrounding the military airfield of Quakam, in 1945. Lebou villages and territories had suffered constant subtraction and shifting, being pushed beyond the area of Quakam. The population grew from 92,000 in 1939 to 382,000 in 1960 (FREUND, 2007: 66) and to the present day estimated over a million people within the city borders and nearly two and a half million in the metropolitan area.

Notwithstanding the long historical processes that bound the fate of these two cities together, since the dawn of mercantile globalisation round the Atlantic, aviation stands out as the key point of approximation as concerns the physical marks left on their spatial configuration to this day. Geographic proximity was the crucial point at the time of the heroic transatlantic flights in the 1900s and 1930s, and even more dramatically so, in the 1940s.

In both cities, other than the facilities demanded by the economic mechanisms of the post-industrial revolution world, such as a railway network and a large-scale harbour, important urban equipment installed in the early 20th century – the hydroplane base and airfields – are there to make the Atlantic air crossing feasible. Various aspects render such equipment highly and similarly important in the two cases as pointed out by Teixeira (1917: 256): in both cities the harbour, the railway termini and the hydroplane base are closely linked in space thus impacting strongly the coastal areas where they are located; the airfields although sited at a considerable distance from the urban limits at the time, become attraction poles for the urban growth, especially during and after the War.

The geopolitical circumstances of Natal and Dakar at the dawn of aviation against a background of a continuously exacerbating process of social differentiation and distribution within the urban milieu will shape their configuration, allowing for the retrieval of marks which reveal how the human action over the territory has engendered unequal levels of accessibility and diverse modes of centrality.

3. MATCHING HISTORICAL RECORDS AND DIACHRONIC SPACE ANALYSIS – THE PHYSICAL IMPRINT

In previous research phases, the topological accessibility of streets in Natal and Dakar was collated to information about evidences of human activity and social cleavages, stemming from the notion that high topological accessibility is an indicator of consolidated or potential centrality (Hillier and Hanson, 1984), understood as a concentration of diversified activity. Contemporary sources – photographs, live and virtual (google images) observations – as well as iconographic and textual records from earlier times were examined in search for the physical aspects of these places, for signs of economic status, for the presence of buildings that might benefit (and intensify) movement of pedestrians and vehicles in open public spaces.

Syntactic measures and references converged to outline a hierarchical contour of topological accessibility that shaped occupation and revealed the material imprint of actions (or their absence), which structured the urban milieu and defined the social distribution of inhabitants in both cities. Accessibility anchored the formation and transformation of centralities, which were unequally appropriated by social groups, and responded to different needs and possibilities being, in turn, instrumental for redefining occupation, social distribution, configuration and so on.

Having confirmed the confluence of axial accessibility and references about the urban occupation and expansion from the 19th to the late 20th century in both towns, we proceeded
to explore space configuration through later, more detailed representation procedures with the aim of investigating relations that might have escaped axial analysis.

In the diachronic configuration analysis of axial maps, future occupation and new centralities that would relate to the global spatial structure at consecutive time periods were indicated by expansion axes that anticipated them. The segment analysis confirmed and refined those findings, adding nuances concerning the development of most potentially passed-through thoroughfares and, by fine-tuning findings using metric scales, signalled the presence of simultaneous centralities related to the demands and circumstances of diverse social spheres.

Linear representations of Natal have been explored as a basis for various studies since the 1990s. The ones examined here represent the town configuration in 1924, c. 1940, c.1970 and 2002. The earlier representations were based on a town plan commissioned by the government of Rio Grande do Norte, in 1924, to subsidise the water and sewage services. Only the streets sided by continuous buildings, as shown in the plans, were considered for the 1924 linear representation; these, plus planned and unoccupied streets (dotted lines), made up the 1940 (circa) representation, considering that it was round that time that they became more densely occupied (Figure 1a). Natal’s representation of approximately 1970 was constructed over a large blueprint – a patchwork made up of successive updating amendments – courtesy of the state water and sewage supply company². The 2002 map was drawn over a digital base issued by the municipality administration of Natal.

The first linear representation of Dakar used in our research was drawn over images displayed by Google Earth in 2012. Lines were erased from this representation to model the city in 1930, 1945 and 1964, according to historical maps that were gradually found along the phase of data collection. In this process, some simulation was necessary. The best cartographic representation of Dakar immediately after its independence in 1961 – a city plan produced by the geographic institute of Paris in 1964 – did not include the north of the peninsula, where a street grid, although sparse, was clearly defined in the map of 1945, indicating the urban expansion move towards north and northeast. The north axes shown in the 1945 map were, therefore, added to the 1964 map. We must concede that this is hardly a faithful representation, considering that in the 19-year break between the two plans, a denser tissue would be expected to have developed there (figure 1b). However, we believe that by applying such artifice more gains than losses were achieved in terms of representation.

The current segment analysis for Natal and Dakar was hence based on those previously explored axial maps, whose findings shall be briefly exposed next, since they were confirmed by the segment analysis.

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² Companhia de Águas e Esgoto do Rio Grande do Norte - CAERN. In the 1990s, CAERN’s geographic information system was being created so that this (and other) blueprint was still being used as reference for managing the water and sewage service.
Figure 1 - Cartographic bases: A - Natal in 1924 (only roads sided by building representation considered) and 1940c (all roads considered) (top); B - Dakar in 1930, 1945 and 1964 (bottom)
3.1. NATAL’S CENTRALITIES: SHIFTING, EXPANDING, MULTIPLYING

In Natal, the town foundation nucleus – Cidade Alta – “the high or upper town” sited on the hill top facing the river, concentrates all highly accessible axes until around the mid-19th century when the most integrated road is that which connects Cidade Alta and Ribeira, “the riverside or lower town”, by the river’s edge, where the harbour was (and still is) located.

The strong magnet of the harbour and later that of the railway and the hydro aeroplane base concur to turn the lower town into the heart of the urban scene until around the 1950s, and very especially during the war years. Even though regular space syntax analytical procedures fail to account for accesses through water, rail and air, the effect that these transportation means exerted over the grid, conducing to its rapid growth, was strong enough to define an accessibility core formed by the street grid that linked the two parts of town. By 1940, when Ribeira was at its peak as the active town centre, most highly accessible streets are again part of Cidade Alta’s grid. The new integration core is located further east of where it had previously been formed, pulled by the highly connected regular grid of Cidade Nova, the residential neighbourhood planned in the early 20th century for the economic elites that, although still a slowly expanding and low density neighbourhood, was becoming increasingly occupied.

Not surprisingly, after the war, the active centre returns to Cidade Alta, partly also due to the shrinking roles of previously key transportation modes located in Ribeira. Trains were being substituted by motor vehicles, hydrotransportation modes ceased to exist in this part of the world, and sea journeys were gradually being ousted by air trips. The new airport, which originated from the military air bases built during the war was located further south (and well out) of town until the late 1970s.

After 1970, following the intense urban expansion in Brazil and in Natal, the accessibility core stretches and partially shifts south-eastwards, alongside and parallel to the road that linked the harbour to the military base and airfield of Parnamirim, site of Natal airport until 2014. Scattered within the city’s street grid and in its fringes, poor residential enclaves appear, thickens and multiply, almost always configuring spatially segregated, labyrinthine tissues.
The morphological imprint of Natal's expansion along the 20th century examined by means of diachronic segment representation confirmed findings from previous axial analysis, contributing a few points worth mentioning. The accessibility calculation (normalised integration – NAIN, figure 2) exposes an urban tissue that encapsulates and conducts accessibility along certain directions leaving out huge parts of town. It is worth noting, for instance, the vast tissue of highly integrated segments that spreading from the east side of town – Lagoa Nova, Alecrim, Tirol and Petrópolis (the last two neighbourhoods being part of the former Cidade Nova) is channelled into a southeast (eng. Roberto Freire avenue) and a southwest (BR101) line. Most of what lays out of the large integration core or away from the cone formed by these southeast-southwest-running lines present the greens and blues of segregation.

The representation of most potentially passed-through thoroughfares (normalised choice – NACH, figure 3) shows that the 21st century main road structure, although clearly defined in the 1970s, appears to have suffered a reductive process which shrank (in relative terms) the number of roads with high potential through-movement in the central area, strengthening the main road circuit.

In the early 21st century grid structure represented (as segments) within a catchment area of 1200m (figure 4d), two cobwebs of warm colours signal centralities in the north and southeast halves of town. This contrasts with representations of previous expansion phases, when there would be only one town centre, topologically speaking, that of 1970 being the most widespread. The southeast centrality spans from the regular grid of Petropolis/Tirol to the tightly woven tissues of Lagoa Nova and Alecrim, being, in fact, a faithful representation of Natal’s active centre at metropolitan scale as this area concentrates the most volume and variety of urban functions and uses (figure 5-top).

The representation also catches the active centre of Parnamirim, the tourism and leisure compound of Ponta Negra, and the suburban centres of Neópolis and Felipe Camarão, which are, all of them, centralities, although of different natures and social meaning.

The accessibility scale, therefore, picks up well established centralities as concerns movement (vehicular and pedestrian) and functions (number and variety of non-residential uses), as, for
instance, the important arteries of Bernardo Vieira and Salgado Filho avenues (figure 5 bottom left). But the red-orange-yellow segments also pick up crossroads on which a modest array of first need facilities – supermarket, chemistry, etc. – concentrates (figure 5-bottom). This appears to relate not only to differences in the functional nature of those centralities or to the socioeconomic profile of the area’s residents, but also to demarcate temporal stages of the city expansion and transformation, by signalling a suburban centrality of fairly recent formation that will most probably be embodied in the larger metropolitan active centre in the near future (Vaughan, 2015), or become a large active centre in its own right.

Figure 4 - Accessibility within a catchment area of 1200m (integration 1200m) in Natal. 1924 (a); 1940 (b); 1970 (c); 2002 (d).

Figure 5 - Centralities of diverse scales and functions in Natal: (top) Felipe Camarão, Potengi, Aecrim (Bernardo Vieira av); (bottom) Neópolis, Ponta Negra, Lagoa Nova (Salgado Filho av.).
3.2. Dakar’s Centralities: Shifting, Expanding, Multiplying

In Dakar, high topological accessibility navigates from the Plateau – to this day the formal city centre – to the Medina, spreading northwards from there: northwest towards the airfield of Ouakan; north until reaching the crossroads that branches west to the airport of Yoff, and east into the road to Rufisque; and northeast, bifurcating into a route to the hydrobase of Bel-Air and another running past it towards Hann.

Round 1930 the accessibility core was formed by the tightly knitted street grid of the Plateau. Poor residential settlements occupied low accessibility enclaves within the main street grid and especially in its fringes (Figure 6a). The long highly accessible Pasteur/Jean Jaurès avenue (figure 6A) runs across the grid, bordering the Plateau's integration core, and joins the likewise Blaise Diagne avenue that transects the Medina, signalling the northwest expansion and the shift of topological accessibility towards Quakan, to be confirmed in the segment representation of 1945 (figure 6b).

By 1945, besides the very integrated Blaise Diagne avenue (Figure 6b), the north sector of the Medina contains highly accessible axes that foretell the dislocation of accessibility northwards and herald the occupation of the large central area of the Peninsula after the war. Sparse patches of buildings near the airfields of Quakam and Yoff strengthen the attraction power exerted by them. The villages of N’Gor, Yoff and Cambérène remain isolated, flimsily connected to the overall spatial structure by a few lines.

In the segment analysis calculated to gauge potential through accessibility (normalised choice – NACH, Figure 7d), the two expansion axes that stemming from Dakar-ville, the town centre, stretch along the coast to the northwest and northeast of the Peninsula, flank the areas where the airfields of Quakan and Yoff were established. A line bisects the angle formed by...
the two expanders, defining a third axis in post-war Dakar (1964 map, Figure 7c). Autoroute N1 will connect the wide central area of the peninsula gradually to be occupied by residential neighbourhoods, mostly low cost at first, then housing estates for the middling sectors, setting the founding grounds for what is referred to as Great Dakar. In the late 1960s, the city comprises four zones: Dakar-ville, the old and to this day established city centre; Great Medina; Great Dakar; and the Industrial Zone. The latter includes the railway network area, the dockland and the industrial sector, being linked by the centre-Northeast axis running towards Rufisque (Figure 08).

Figure 7 - Potential through accessibility (normalised choice – NACH) in Dakar. (a) 1930; (b) 1945; (c) 1964; (d) 2012.

In the segment map showing the most passed-through roads in 1930 (figure 8A), three of the routes that demarcate the urban limits in 1862, 1908 and c. 1915, according to Teixeira (2017), based on Seck (1970:149) appear highlighted: (1) the south-north running Av. Du President Lamine Gueye (though a pale blue), the urban borderline in the 19th century; (2) the lines west of it connecting the present day avenues Pasteur/Jean Jaurés, Petersen and Blaise Diagne; and (3) the southwest end of avenue Malick Sy, that sat the boundary beyond which nothing could be built in the early 20th century.

In the likewise representation of 1964, two other boundaries are highlighted: (1) the Boulevard President Habib Bourguiba, which limits the northern urban area with continuous grid at the end of the war (figure 8C); and (2) the curved line running from the city centre towards northwest – current Voie de l’Alternance or Route the Front de Terre that demarcated the urban boundary, according to Seck (apud Teixeira, 2017), in 1967.
Figure 8 - The linear skeleton of potential through accessibility (choice) in Dakar. A) 1930; (B) 1945; (C) 1964; and (D) 2012.

Figure 9 - Accessibility within a catchment area of 600m (integration 600m) in Dakar. A) 1930; (B) 1945; (C) 1964; and (D) 2012.
When the grid structure is calculated to account for relations within a metric distance of 600m, various simultaneous centralities emerge. In the 1964 segment map, Dakar-ville, the traditional centre on the Plateau surfaces as a tightly knitted central grid (figure 9C). In the Medina, centrality appears diffused throughout its regular grid and in the north settlements – round Grand Dakar, Biscuiterie, Dieuppeul – curved ways running south-north retain high topological accessibility within the partially radial layout. 21st century Dagoudane Pikine (2012 map, Figure 9D) contains some nuclei of high topological accessibility, perhaps the strongest in the whole urban structure, within a catchment area of 600m. Grand Yoff, Yoff and Cambréne also comprehend webs of highly accessible streets defining a local integration core, and in the villages located in-between the present Internacional Aeroport Léopold-Sédar-Senghor of Dakar (in Yoff) and the old airfield of Ouakam, an embryonary integration core indicates the formation of a sub-centre.

![Figure 10 - Diverse centralities in Dakar: (Top) Grand Yoff, Biscuiterie, Pikine; (bottom) Grand Dakar, Medina, Plateau. Source: Google Maps Street View, access on April 2017.](image)

4. IN THE GUISE OF CONCLUSION

Why was it that Natal and Dakar, despite being abundantly cited in the contexts of the war and the early stages of transatlantic air crossing have deserved so little saying about the material urban expression of their parallel historical roles? The desire to start filling this gap motivated this brief insight, sparked off by the intent to weave a comparative historical account of these two cities separated and united by an ocean, that set in motion the study conducted by my friend and fellow researcher Rubenilson Teixeira (2017).

Teixeira’s study, of which this morphological analysis is but a complementary contribution, furthers the understanding of aspects from our common South American and African historical legacy, highlighting the fact that notwithstanding their huge sociocultural differences, the roles Natal and Dakar played in the world political scene, which are closely related to the physical attributes of their natural sites, combined to the social logic of space in national and global capitalism have left common marks in their urban form. Some of the marks discussed here – mainly the ones pertaining to the street configuration – reveal ways in which space has been handled over the 20th century to secure accessibility privileges that are unequally reached by people of distinct social stand, and ways in which those excluded from the privileged bits overcome segregation by building up other modes of centrality. Out of the myriad of aspects not addressed here it would be valuable to examine common features concerning the building ensemble in the two cities, particularly those of the peripheral centralities that appear to bear so many common traits at a first look. Another is the explorations of possible reasons why
whereas in Natal the metric distance of 1200m coincides better with multiple centralities, this is better attained in Dakar by a metric ratio of 600m. Would that mean that the more regular grid of Natal’s configuration is less favourable to pedestrian movement than that of Dakar? Yet another is the examination of the nature of these multiple centralities that at face value appear to be split into those for the rich and those for the poor, but that we know to be much more complex than that in sociocultural aspects, with modes of interface among residents from distinct backgrounds and between residents and visitors, being only one of the most obvious aspects demanding investigation.

Geographic features and proximity at a continental scale were crucial factors that triggered the destinies of the two cities in similar lines from the start, being intensified at the time of the early transatlantic aviation routes. It was, however, the human action directed at setting people and cultures apart the matrix that shaped and carries on shaping accessibility and centrality in the two cities, of which the purpose to persuade the rich and thrust the poor out of town in the planned residential neighbourhoods of Cidade Nova (Natal) and Medina (Dakar) are highly emblematic examples.
REFERENCES


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SPATIAL CONFIGURATION AND REGIONAL ECONOMY

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ABSTRACT

The second most important economic pole in the State of Rio Grande do Sul, Brazil, corresponds to an agglomeration of thirteen cities located in its northeast zone. They are mid-sized cities whose municipalities concentrate seven per cent of the state population and fifteen per cent of the State Gross Product.

In 2013, this group of municipalities, despite not exactly presenting the main characteristics that commonly describe a metropolitan phenomenon, such as large population, commuting and conurbation, was institutionalized as the Metropolitan Region of Serra Gaúcha - MRSG, when political reasons overcame technical delimitation criteria.

However, the territory in between those cities shows interesting peculiarities which deserve to be examined face to the model of the post-industrial city, spreading over diversified, fragmented, heterogeneous, dense or diffuse zones with different growth dynamics. Relations between accessibility and land use at different scales over MRSG territory need to be better understood on this contemporary context. The investigation is aided by recent developments of Space Syntax tools, which have been efficient to describe large complex systems.

The present paper brings part of the results of the ongoing exploratory research about spatial configuration and regional structure, which aims to review criteria for delimitation of metropolitan areas in Brazil. It uses a geo-referenced data base which contains over two hundred thousand plots of electric energy supply for the great majority of the activities developed in the region. These locations were correlated to syntactic measures of closeness and betweenness centrality based on the whole axial segments network, in order to investigate land use and occupation patterns representative of a contemporary territoriality in the southern part of the country. Demographic census data were also used to verify correlations between income and location.

The results point out to significant centrality changes when municipalities are globally analyzed; to the existence of industrial activity being developed in rural areas; and to the fact that
residential areas are not only inserted into urban zones but also in the rural territory, although the highest family incomes are more concentrated in the inner city.

KEYWORDS
urban and regional planning, spatial configuration, space syntax

1. INTRODUCTION
In a general sense, the purpose of regional planning actions is to reduce the imbalances between territories at different scales, in order to promote social and economic development, with better labor, housing, health, leisure and culture conditions for the population.

France, England, Italy, Sweden, and other countries where regional planning has a long tradition, present nowadays significant results regarding to industrial and culture decentralization, agriculture modernization and tourism development (Tavares, 1996).

Despite being one of the most important economies in the world, Brazil presents high levels of social and economic inequalities among municipalities, what reveal a lack of effective up to date regional policies (Neto, 2009). In the 60’s, they were somehow implemented regarding to the macro-regions of the country, much more based on fiscal incentives for industrial development poles than focused on the municipalities possibilities and sustainability.

In the last decades, the regional issue, in Brazil, has been directed mostly to the metropolitan problem, which is strongly marked by the fact that there are strictly three government levels in the country: the municipal, the state and the federal. The regions themselves do not have institutional power, what makes integrated planning actions a difficult task.

However, it is argued, there is an emerging necessity of Brazilian communities to belong to some kind of institutional association, what results in political initiatives to create metropolitan regions. In fact, there are nearly 70 metropolitan regions in the whole country and most of them were delimited with basis in unclear criteria. Excessive number of municipalities, overlapping delimitation, unjustified inclusion and exclusion of cities are the components of a conceptual distortion and misunderstanding about the metropolitan phenomenon.

Naturally, the first step on any possible regional delimitation approach of the territory is to be conscious of the environmental, social and economic issues, which extrapolate the municipal scale, and that are obviously related to the state and federal context.

In fact, regional delimitation, is not a simple process, mainly when it deals with the complexity of urban dynamics. Some authors use to say that delimitation happens to be discriminatory, in a certain way (ABRANTES et al, 2010). Actually, it is very difficult to draw a line separating a diversified territory with a fragmented and heterogeneous occupation, formed by dense or diffuse zones with different growth dynamics, from an exclusive rural one.

However, in some way this is necessary to be done, in order to be put in evidence where the strongest dependence relations between parts and the whole happen to be. This is the case of Metropolitan Region of Serra Gaúcha - MRSG, which is here taken for a deeper investigation. It was recently instituted, by the State of Rio Grande do Sul Government, based exclusively in the notion that the agglomeration of municipalities was important for the State because of its intense industrial activity. Other important aspects were not taken into consideration like population density, urban occupation continuity and commuting which indicates a metropolitan dynamics (Ugalde et al, 2015). The ongoing exploratory research, intends to introduce the spatial variable as an element to be considered on the delimitation of metropolitan agglomerations.

So far, parts, on traditional approaches, are taken as surface units such as demographic census sectors, districts or neighborhoods, which do not allow a deeper spatial analysis. Space syntax, combined with GIS tools, offers an interesting methodology supported by a consistent theory for morphological analysis based on space disaggregation and differentiation, which has been efficient for urban and regional structures identification.
This paper aims to present the results of the mentioned research, regarding to three of its main goals: to identify the global spatial structure of RMSG from the emergence of patterns of accessibility, centrality and distribution of important economic activities; to verify the degree of dependence of each municipal spatial structure from the global regional structure and to analyze the possibilities of urban expansion face to natural conditioning, particularly regarding to topography. Main industrial location will be examined and correlated with accessibility patterns, because of its importance in the regional economy and to contribute for a discussion about the rural / urban dichotomy in the studied territory.

2. BRAZILIAN INSTITUTIONAL CRITERIA FOR THE DELIMITATION OF METROPOLITAN AREAS AND URBAN AGGLOMERATION

The first Brazilian metropolitan regions were institutionalized based on studies developed by the official statistics and geography institute (IBGE), in 1969, aiming to conceptualize the metropolis, metropolitan areas and metropolitan regions as well as to stipulate delimitation criteria, which resulted in three categories: demographic, structural and integration.

Regarding to the demographic criteria, the central city should not have less then 400,000 inhabitants, according to 1970 Census. Its population density should be more than 500 inhabitants / km² and satellite cities’ should not be lower than 60 inhabitants / km². There also should be a variation of at least 45% on municipal population from 1950 to 1960.

Structural criteria, regarded to economic aspects and commuting, required that 10 % of the population of each municipality should be working in industries or number of commuters not to be less than 20% of the dormitory cities population. Besides that, the regional Industrial Gross Product should be three times higher than the Agricultural Gross Product, considering the group of municipalities within the region.

The integration criteria states that at least 10% of each municipal population should take two-way daily trips, either to the central city or to the other ones, besides the number of phone calls to the central city, which should be over 80 per terminal.

One of the first metropolitan regions delimited in the country was the Metropolitan Region of Porto Alegre, in 1967, when 14 municipalities fulfilled those requirements plus the ones regarding to urban occupation continuity and functionality, that is, some infrastructures, facilities and services were offered only in some cities. Meanwhile, other rules were approved regarding to the inclusion of municipalities in pre-existing regions, which will not be mentioned here due to the article extension limits.

In 1988, the Federal Constitution designated the states to create and regulate metropolitan regions but didn’t include any criteria for their delimitation. The lack of rationality on many state administrations led, for example, to the zoning of the whole territory of the State of Santa Catarina into metropolitan regions.

More recently and in order to avoid these distortions, a federal law, called “Metropolis Statute” introduced new concepts based on influence regions of cities. However they are not very clear and directly applicable in complex territorial situations.

The Metropolitan Region Serra Gaúcha fulfills partially the criteria mentioned before. The main city of the region is Caxias do Sul with a population of approximately 470,000 inhabitants. However its population density is not higher than 286 inhabitants / km² whereas only six out of the thirteen municipalities have densities over 60 inhabitants / km² (Figure 1).
Table 1 shows the percentage of the Economic Active Population working on factories what reinforces the industrial character of this region, in such a way that the industrial Gross Product is 17 times higher than the agricultural value. Therefore, it seems that there is no doubt about the economic profile of those municipalities. However an important criterion was not attended. The amount of commuting trips for work and educational purposes, except for Carlos Barbosa, Flores da Cunha and Garibaldi, remains below 10% of their total population, according to the demographic census of 2010. Later in this article, an spatial analysis regarding to conurbation, which is, together with commuting, fundamental for a metropolitan region delimitation will be done.
Table 1 - Economic Active Population on industrial activity in MRSG (Source: IBGE).

<table>
<thead>
<tr>
<th>MUNICIPALITY</th>
<th>EAP (habitants)</th>
<th>EAP on industry</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANTÔNIO PRADO</td>
<td>13,906</td>
<td>4,337</td>
<td>31</td>
</tr>
<tr>
<td>BENTO GONÇALVES</td>
<td>91,432</td>
<td>37,089</td>
<td>41</td>
</tr>
<tr>
<td>CARLOS BARBOSA</td>
<td>26,406</td>
<td>12,504</td>
<td>47</td>
</tr>
<tr>
<td>CAXIAS DO SUL</td>
<td>354,737</td>
<td>153,465</td>
<td>43</td>
</tr>
<tr>
<td>FARROUPILHA</td>
<td>55,969</td>
<td>25,720</td>
<td>46</td>
</tr>
<tr>
<td>FLORES DA CUNHA</td>
<td>24,224</td>
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<td>39</td>
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<td>GARIBALDI</td>
<td>27,865</td>
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<td>IPÊ</td>
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<td>MONTE BELO DO SUL</td>
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<tr>
<td>SANTA TEREZA</td>
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<td>251</td>
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<td>SÃO MARCOS</td>
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<td>7,839</td>
<td>44</td>
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<td><strong>TOTAL</strong></td>
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<td><strong>264,708</strong></td>
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</tr>
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</table>

3. THE RURAL-URBAN DICHOTOMY AND “O NOVO RURAL” IN BRAZIL

The previous paper about the mentioned ongoing research brought a brief review about the basic characteristics of metropolitan areas in a context of globalized economy as well as the importance and possibilities of regional delimitations (Ugalde et al, op cit.). The metapolis was described as the model of fragmented, heterogeneous and diffuse post-industrial city spread over a territory that gradually loses its characteristics of a typical rural environment.

Caiado and Santos (2003) verified that the main feature of the socio-spatial transformations is the conurbation growth together with a weight reduction of agriculture activities on employment and income of the families living in rural areas in the State of São Paulo, Brazil. The structuring and expansion of real estate market, organized in different stages of the merchant capital reproduction (land subdivision, construction, incorporation, financing and sale) intensified verticalisation with residential and corporative buildings, as well as the implantation of medium-class private gated communities on peripheral neighborhoods without infrastructures. Slums appearance on almost all small cities regardless their size became the expression of a contradictory urbanization pattern, resulting from the urbanization of the capital and to the capital.

Not only urban areas have changed their features. Regarding to rural areas, agriculture and cattle raising achieved higher levels of technology, demanding less manual work and higher
levels of instruction in the rural labor market. However there are still traditional agriculture areas where low technology practices are still adopted. The fact is that they are not able to describe and explain the demographic and labor market dynamics anymore. According to the authors, other rural activities, not related to agriculture, are emerging from the increasing urbanization process of the rural territory such as: accommodation and hospitality, tourism, leisure, environment preservation, floriculture, crafts, and others.

Tourism in rural environment comprises spa resorts, defined as *places devoted to enhancing overall well-being through a variety of professional services that encourage the renewal of mind, body and spirit*, rural convention centers, training places for executives, ecological tourism, adventure tourism, business tourism and others. This economic sector increases territory valorization, through environmental, historical and cultural protection. Family small enterprises can offer products to specific groups of consumers that, for being small, do not stimulate big companies to be in the business.

Blakely and Bradshaw (1985) emphasize that, despite all these changes, rural policies are still focused basically on rural population segregation including transportation, housing, education and health improvement. Planners and authorities are not conscious yet about the new necessities of rural zones, related to a post-industrial society. One of these necessities is, for example, a sustainable zoning for a more diversified land use based on environmental protection.

In the next sections, considerations about rural territory of MRSG will be made regarding to industrial activities.

### 4. THE COURSE OF THE RESEARCH

The previous paper brought to discussion the syntactic analysis of five municipalities belonging to MRSG: Caxias do Sul, Farroupilha, Bento Gonçalves, Garibaldi and Carlos Barbosa (Ugalde et al, op.cit.). The global space integration of the agglomeration was analyzed aided by Depthmap (Varoudis, 2012) and ArcGIS software. After processing the global integration of each municipality up to the limits of their boundaries, it was possible to observe changes on closeness centralities when each one of these parts were put together as a whole.

Afterwards, a considerable set of land use data was obtained to overlay the configuration, allowing an overview of possible relationships between syntactic measures and basic urban activities related to commerce and services, industry and housing. For that purpose, approximately 52,000 geo-referenced water consumption measure points were provided by the State Sanitation Company (CORSAN-RS). The number of units linked to each point also permitted a preliminary analysis of activity densities.

For the present analysis, approximately 232,000 geo-referenced electric energy consumption measure points were provided by RGE, the electric energy supplier for the region. Each point is categorized according to the National Classification of Economic Activity, what makes possible to relate activity locations with syntactic variables. This set of data represents an advantage compared to water consumption measure points because activities located in rural areas might not need a public water supply, but they are totally dependent from electricity.

Presently, the axial map of the whole region, composed by 13 municipalities, is complete. It consists of approximately 93,000 axial lines and 142,000 segments. The necessary operation for the analysis were processed by Depthmap X in combination with ArcGIS, and QGIS integrated to Space Syntax Tool Kit (Gil et al, 2015)

### 4.1 THE GEOMORPHOLOGICAL ANALYSIS

The course of the research firstly leads to a natural environment analysis because it becomes necessary to evidence the main characteristics of the MRSG site, specially regarding to geomorphologic aspects.
Regarding to the geomorphological characteristics, the study area is inserted in the Geomorphological Region of the Planalto das Araucárias, belonging to the Geological Survey of Paraná (RADAM, 1986). The Geomorphological Region of the Planalto das Araucárias is characterized by relief forms carved in acidic and basic volcanic rocks of the Serra Geral Formation (CPRM, 1998; IBGE, 1986).

According to Pinheiro (2000), the geomorphological unit of Serra Geral, in turn, is subdivided into two compartments, Aparados da Serra and Área Serrana (in which the study area is inserted). The Área Serrana is characterized by forms of relief marked by deep and intense dissection with marked structural control, occurrence of structural grooves of various orientations and fluvial channels adapted to them. The main drainage axes refer to the Caí, Turvo and especially the Taquari-Antas rivers.

In this context, MRSG presents variants, from fairly rugged relief areas, mainly in the central and southern portions of the study area, where the Caí and Taquari-Antas rivers are located, where edges and strands of great slope can be observed, to areas with smoother relief, in the northern portion.

Figure 2 shows how environmentally conditioned the territory of MRSG is, specially by Antas River, which practically divide the territory in two parts: municipalities of Ipê and Antônio Prado, located in the northern part and the rest of them in the southern part. High slopes, specially along the main water courses also constraint urban occupation.
Figure 2 - The image in the left shows the superficial drainage natural system (in light green) with Rio das Antas (in blue). The image in the right position shows the layer of slopes above 30% (in red). Source: Produced by Geographer Vagner Mengue with information from IBGE processed by software ArcGIS.
4.2 THE CONURBATION ANALYSIS

A significant feature of the metropolis is the urbanization crossing administrative borders on the territory. Measuring conurbation is not a simple task. The continuity of the territory occupation is different according to the scale of observation. Two hundred meters is an international parameter as being the maximum distance between buildings, but what density of these buffers can be taken as a continuity of occupation. Figure 3 shows the circles with a 100 m radius delimiting 200 m from one spot to another, in two different scales of observation: 1/100,000 and 1/10,000.

Another aspect to be considered is that, according to legislation, the question to be answered is if there is conurbation among municipalities. Therefore, municipality is the spatial unit formally considered. Although this question is not properly adequate to the complexity of the spatial phenomenon, the density of occupation along borders was examined. Legislation establishes that state government should regulate land subdivision projects located inside a 500 m buffer.
along municipality borders. This distance was then taken for the evaluation. The result is illustrated on figure 4. Actually, there are conurbation zones and, consequently only parts of the borders can be considered to be linking two or more municipal urbanization processes. The main borders are among Carlos Barbosa, Garibaldi, Bento Gonçalves, Farroupilha and Flores da Cunha.

Regarding to other possibilities of measuring potential conurbation under the syntactic point-of-view, there should be remembered the studies proceeded by RIGATTI (2009), and RIGATTI and UGALDE (2007). Those contents are still being discussed in order to subsidize the final research report.

4.3 THE SYNTACTIC ANALYSIS

The part-whole problem is brought to discussion in the research project because its main purpose is to identify a spatial structure of the MRSG and to observe if it is strong enough to justify the institutionalization of a regional entity of thirteen municipalities. For this approach, space disaggregation is essential to be done so that the complexity of spatial relations can be captured. Therefore the axial map, composed by approximately 93,000 lines, represent the road and street regional accessibility grid.

The degree of dependence from each “municipal part” to the “regional whole” can be evaluated by closeness centrality and betweenness centrality, which correspond, in Space Syntax, to integration and choice measures.

Figure 4 - Municipal borders and intensity of territory occupation per linear kilometer. Source: Produced by Geographer Vagner Mengue with information from IBGE processed by software ArcGIS.
Figura 5 shows global integration ($R_n$) of MRSG. The color gradient, from red to dark blue, indicates the rank of integration values from the more integrated axial lines to the more segregated ones. Thus, on one hand, we can observe a high concentration of integrated lines relatively close to the central part of the configuration, practically corresponding to the cities of Caxias do Sul and Farroupilha. Certainly, this happens not only because that is the zone of the least topological distances from each line to all the other ones, but mainly because a large quantity of long and highly connected lines are located there. Accessibility is largely privileged, what reflects on high densities of population and activities related to commerce and services.

On the other hand, there are zones of high segregation, not only for being near the edge of the configuration, but mainly for being parts poorly connected to the whole. That’s the case of Antônio Prado and Ipê, which are practically separated from the rest of the municipalities because of Antas River.

The global integration visual analysis based on Depthmap output evidences a difficulty as far as the representative colors get more distant from the red color. It becomes more difficult to distinguish the differences among global integration values. Local integration ($r_3$) was tested as an option to identify more localized centralities. In fact, they emerge as shown in Figure 5. However, the algorithm measures the importance of each line up to 3 direction changes or 3 depth steps. Therefore there is a surface limitation within the global configuration and it does not reveal properly the global integration gradient in those parts of the whole which are more distant from the center.

In order to better visualize the global integration nuances, a simple method is created for the purpose of this investigation: after running the algorithm for global integration on QGIS, the group of values of each municipality are selected in order to be processed individually. Because the axial map is geo-referenced, it is possible not only to better visualize global integration variation but also to compare the change of centralities when the municipality is embedded in the regional configuration. Figure 6 shows the result.
On one hand, the more integrated lines in each municipality tend to be closer to the federal and state highways which, in most cases, are the straightest connection between cities. The least direction changes decreases topologic distances and those spaces become the preferred locations for attraction. In Figure 07, some examples of this increasing tendency can be verified.
Some smaller urban concentrations, like Pinto Bandeira and Nova Pádua, which are not directly accessible by those highways, tend to be polarised by larger concentrations as Bento Gonçalves and Flores da Cunha, respectively.

Another contribution to the discussion about how each municipality is configurationally affected by the global regional system, was based in a comparison between global integration of each municipality with their global integration when embedded in the regional whole. Figures 8 and 9 illustrates four characteristics of centrality change in Garibaldi, Caxias do Sul, Ipê and Monte Belo do Sul.
Figure 8 – Global integration (Rn) of Garibaldi and Caxias do Sul in two different contexts. On the left side, integration up to the borders of the municipality. On the right side, municipality embedded on the global regional system. Source: Assembled by Architect Cláudio Ugalde. Data processed by Space Syntax Tool Kit for QGIS.
Figure 9 – Global integration (Rn) of Ipê and Monte Belo do Sul in two different contexts. On the left side, integration up to the borders of the municipality. On the right side, municipality embedded on the global regional system. Source: Assembled by Architect Cláudio Ugalde. Data processed by Space Syntax Tool Kit for QGIS.
The urban concentration of Garibaldi, the city itself, is in fact, the most integrated area of the municipality and is located relatively close to RS 122 and BR 453. This is very clear. However, there is a group of lines which are more integrated than the ones in historical center, influenced by an even more topological proximity to the rest of the system, what is propitiated by the highways. Thus, there is a centrality change process in course in so far as the urban expansion connects to them.

The city of Caxias do Sul is in fact the most integrated one, not only in the regional configuration but also when centrality is measured up to the limits of its own territory. Besides some reasons pointed out before but also for being intersected by BR 116 and BR 453. The first one, built in 1941, attracted urban expansion to the east, regarding specially to industrial location and the second one, built in 1972, have supported mostly logistic and large size commerce.

Another interesting situation comes up with the case of Ipê, where the original urban core acquire importance at the regional scale. In the individual analysis, centrality is located a little further north, where, in fact, the level of occupation and activity is very low. On the contrary, Monte Belo shows a significant centrality displacement from the historical urban core to a parallel road, which is the shortest route to Banto Gonçalves, where different land uses are consolidating.

Space Syntax presents another important measure, significantly correlated with through movement: choice. The measure highlights the most used spaces which tend to be least angle paths taken on journeys between each pair of segments in the spatial configuration (Hillier 2010).

Based on the reasonable idea that easy through movement within the city-region is an strategic element for development, the choice network was identified in order to examine how present it is in the territory of each municipality.

According to Jiang (2009), a quantity follows a power law when the probability or frequency of its value varies inversely as a power of that value. This is what happens regarding to the potential quantity of through movement in a spatial configuration. Based on previous investigations (Newman, 2005), he argues that majority of traffic, approximately 80% occurs in the top 20% of streets and the top 1% of streets account for more than 20% of traffic. Least angle choice has been powerful on expressing this phenomenon.

In Figure 10(a), 5% of the highest choice values is represented. Practically the whole highway system was captured, what reinforces the tendency of the mentioned municipal centralities change.
Table 2 shows the number of segments of the choice network (10% of the highest values) belonging to each municipality. The purpose of this statistics is to observe how connected each municipality is to the mobility regional network, potentially used for the transportation of passengers and products. On one hand, it calls attention that Monte Belo do Sul, with a small urban core, has a number of choice network segments / km² as expressive as Bento Gonçalves, while Caxias do Sul has a much lower quantity per square kilometer of its territory. Of course, these means have to do with the municipal surface, but the difference is the choice mean value of the segments. Thus, the routes inside Caxias do Sul are much more potentially used than the ones in Monte Belo. Any way, the distribution of choice lines over the territory should be investigated in order that the relationship among municipalities regarding to large scale movement can be better evaluated.
<table>
<thead>
<tr>
<th>MUNICÍPIO</th>
<th>Surface (km²)</th>
<th>Number of Segments</th>
<th>Segments / Km²</th>
<th>Choice Mean Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANTÔNIO PRADO</td>
<td>347.3</td>
<td>687</td>
<td>1.98</td>
<td>627,991,754.60</td>
</tr>
<tr>
<td>BENTO GONÇALVES</td>
<td>273.9</td>
<td>1562</td>
<td>5.7</td>
<td>352,004,617.18</td>
</tr>
<tr>
<td>CARLOS BARBOSA</td>
<td>229.8</td>
<td>569</td>
<td>2.48</td>
<td>173,412,998.98</td>
</tr>
<tr>
<td>CAXIAS DO SUL</td>
<td>16.1</td>
<td>4780</td>
<td>2.9</td>
<td>540,080,776.23</td>
</tr>
<tr>
<td>FARROUPILHA</td>
<td>361.4</td>
<td>1569</td>
<td>4.34</td>
<td>814,045,498.20</td>
</tr>
<tr>
<td>FLORES DA CUNHA</td>
<td>272.4</td>
<td>944</td>
<td>3.47</td>
<td>841,155,902.74</td>
</tr>
<tr>
<td>GARIBALDI</td>
<td>1.8</td>
<td>653</td>
<td>3.89</td>
<td>572,090,696.10</td>
</tr>
<tr>
<td>IPÊ</td>
<td>598.8</td>
<td>894</td>
<td>1.49</td>
<td>216,969,416.55</td>
</tr>
<tr>
<td>MONTE BELO DO SUL</td>
<td>69.5</td>
<td>359</td>
<td>5.16</td>
<td>155,048,763.43</td>
</tr>
<tr>
<td>NOVA PÁDUA</td>
<td>103.2</td>
<td>225</td>
<td>2.18</td>
<td>183,241,257.19</td>
</tr>
<tr>
<td>PINTO BANDEIRA</td>
<td>105</td>
<td>244</td>
<td>2.32</td>
<td>158,706,681.95</td>
</tr>
<tr>
<td>SANTA TEREZA</td>
<td>73.9</td>
<td>226</td>
<td>3.06</td>
<td>153,604,749.28</td>
</tr>
<tr>
<td>SÃO MARCOS</td>
<td>256</td>
<td>713</td>
<td>2.78</td>
<td>224,235,531.69</td>
</tr>
</tbody>
</table>

Table 2 – Number of choice network segments (10% of the highest values) belonging to each municipality per square kilometer.

4.4 THE LAND USE ANALYSIS

The land use data base available has geo-referenced information about approximately 232,000 geo-referenced electric energy consumption measure points provided by an electric energy company responsible for the service. The basic land use categories were partially analyzed by Ugalde et al (2015) for a group of 5 municipalities in MRSG. For the present paper, the whole metropolitan region is examined regarding to the industrial use divided in the 5 most important categories for the regional economy: leather, machines and equipment, metallurgy, furniture, textile and wine. Besides these products being sold all over, specially the wine, textile and furniture industries frequently also sell their products in showrooms located near by the factories, what attracts tourists and bring jobs to rural areas.

Figure 10 (b) shows the location of the whole set of dots, where an immense quantity of activities in rural zones can be observed. However when the selected categories are highlighted, it becomes clear that, except for the wine industry, according to Table 3, the majority of the dots still overlay the urban areas, what indicates that main industrial activity in the region is either dependent of urban accessibility and urbanization patterns or regulations are still stricted regarding to industrial activity. The wine industry, very representative of the regional economy, seems to be under two circumstances: a necessary location near the cultivation areas and the opportunity of bringing tourists to an interesting rural landscape. However, hospitality and accommodation for tourists are still very related to urban areas.
A 100 m buffer was set along the 20% top values of choice network in order to observe how dependent were those economic activities from a large scale movement grid. Expressive percentages regarding to wineries (100/157) and accommodation (56/73) tend to be located along choice network what suggests a stronger relation between the sector with consumers and suppliers from distant parts of the region besides a more local demand.

### 5. FINAL CONSIDERATIONS

Some issues of the exploratory research were brought to discussion in the present paper. Presently, activity locations analysis cannot be operated with basis on homogeneous territorial units. Complexity resulting from relations, flows, dynamics, competition requires other models to be captured in different territory scales. In a network urbanism perspective, space disaggregated units associated to precise location of activities can lead to the identification of patterns of accessibility, centrality, movement and land use among others. This approach was here attempted to better know the city-region of Serra Gaúcha and how spatially dependent each of its parts depends upon the whole.

If global integration would be taken as a parameter, Figure 5 suggests that the municipalities of Ipê, Antônio Prado, São Marcos, Nova Pádua, Pinto Bandeira, Monte Belo do Sul and Santa Teresa should not be part of the delimitation. However when large scale movement (Choice 10%) network is visualized, the smaller cities appear to be more dependent from the rest of region, meaning that they are more directly connected to the other municipalities, although not so intensively.

The intensity of connections among municipalities presupposes a potential conurbation, once the syntactic model deals with accessibility networks, but not directly with real occupation along them. Densities tend to increase in more accessible public spaces overtime and that is the case of an agglomeration with a great degree of discontinuity of occupation in territories in between yet.

Despite this discontinuity, the territory of MRSG is visibly dotted not only with an immense number of residences and agricultural infrastructure, but also with general retail (318), administrative and public functions (213), sports and leisure activities (85), services (19), specialized retail (15) among others. On the continuity of the research, correlations will be tested between configuration local and global properties with other activities different from industrial ones. Regarding to these ones, it was seen, they are still well correlated to the urban accessibility pattern, predominantly the traditional regular grid.

---

**Table 3 – Establishments of the industrial sector according to urban / rural zoning and to choice network buffering.**

<table>
<thead>
<tr>
<th>Industrial Sector</th>
<th>Wine</th>
<th>Furniture</th>
<th>Metallurgy</th>
<th>Textile</th>
<th>Equipment</th>
<th>Leather</th>
<th>Hospitality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total of establishments</td>
<td>157</td>
<td>216</td>
<td>926</td>
<td>424</td>
<td>983</td>
<td>97</td>
<td>73</td>
</tr>
<tr>
<td>Number of establishments</td>
<td>urb an</td>
<td>rur al</td>
<td>urb an</td>
<td>rur al</td>
<td>urb an</td>
<td>rur al</td>
<td>urb an</td>
</tr>
<tr>
<td>%</td>
<td>36.9</td>
<td>63.1</td>
<td>79.6</td>
<td>20.4</td>
<td>94.4</td>
<td>5.6</td>
<td>99.1</td>
</tr>
<tr>
<td>Included in a 100m buffer along choice network (20%)</td>
<td>100</td>
<td>115</td>
<td>467</td>
<td>254</td>
<td>498</td>
<td>56</td>
<td>56</td>
</tr>
</tbody>
</table>
The main purpose of delimiting metropolitan regions is the governance of public functions which cannot be managed by municipalities in an independent way, such as commuting, natural environment resources and infrastructures going beyond municipal borders. Some of these functions are not sol clearly present in Metropolitan Region of Serra Gaúcha. However, for being still an incipient conurbation process, could be taken as an important fact to create a technical and political environment towards innovation on planning and governance initiatives.
REFERENCES


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ABSTRACT

In order to meet the pressures of a growing population and employment base, a developing city in the Middle East is planning a new public transport system to allow its sustainable growth. Introducing a new mode of public transport to a city that has a complex urban structure and a dependency on car use necessitates specific design responses to inform the station design process. This paper focuses on a study at the micro scale level that addresses the impact of evidence-based design on contextualised architectural station prototypes. Furthermore, it addresses the processes of working with an architectural design office in creating dynamic design iterations. The research here is presented from a perspective of the process of iterative analytical study to real time projects, reflecting on the balance between academia and practice. In order to construct a set of design principles to station locations, three layers of potential movement patterns are analysed using agents based modelling: movement from station exits; movement towards station entrances and background movement generated through the spatial accessibility values of the surrounding context. In that respect, each prototype station has been contextualised to its unique site. Design proposals developed by architectural teams are informed through fine grain analysis of urban features such as pavement widths and signage locations. The analyses also inform the landscape design process through the positioning of street furniture in relation to potential movement patterns as well as the effect of shading and public realm quality through option testing. To integrate stations within their contexts they must have simple entrances and clear orientation from the points of exit. Overall, the dynamic nature of agent based modelling allows for rapid design feedback to occur permitting an iterative process of design development and optimisation.
KEYWORDS
Architectural Prototype, Space Syntax, Micro Scale Design, Dynamic Design Feedback

1. INTRODUCTION

Need for an analytical methodology

Cities in the need for urgent development are facing the challenge of creating sustainable environments through top down design proposals. In order for planned urban projects to adapt to the urban context it needs to consist of well-established conditions where the existing infrastructure can support new design proposals. However, this might not be the case in certain circumstances where the urban context is in the growing process and requires quick adaptation to a proposed urban project. At that point, as the complexity of the project increases, new methodologies are needed to incorporate to improve design development processes. In complex urban design projects, the use of analytical methods is believed to facilitate generating new design ideas, objective testing of design outputs and increasing the potential for successful design results (Karimi, 2012). It is further argued that this can be mainly achieved through a spatial approach. This paper represents a micro scale study of a new public transport system planned in a developing city in Middle East to meet the pressures of a growing population and employment base. In order to help allowing its sustainable growth, the study here proposes an analytical approach creating a design strategy that contextualises architectural station prototypes. It focuses on 72 metro stations to help deliver citywide improvements working with an architectural practice through a dynamic design iteration process. Through the process of interactive design feedbacks, it also reflects on the balance between academia and practice.

With the urge of delivering projects to deadlines, a vast majority of urban planners mainly concern about structural and formal aspects of the design and tend to disregard the unique values of spatial contexts. These failing approaches have been reconsidered by new environment designs aiming to ‘create life’ in cities where the roots of this idea has started with Jane Jacobs (1961) suggesting that there is a link between successfully designed environments and social outcomes. The issue of ‘creating life’ in cities has been further explored through the concept of ‘architectural determinism’ discussing whether spatial environment can be used as a proxy to generate ‘life’. The relation between spatial and social aspects suggests that cities are formed of two parts: ‘a large collection of buildings linked by space, and a complex system of human activity linked by interaction’, namely the ‘physical’ and the ‘social’ city (Hiller and Vaughan, 2007). However, the failure of initial studies seem to be the result of separation of the two and instead, taking ‘cities as one thing’ is further suggested for a more complete way of thinking and analysing urban systems as the sum of both entities. Space Syntax theory, developed in nineteen seventies, focuses on the relationship between space and society, arguing that space has a logic that can be studied to trace social origins and outcomes in a built environment (Hillier and Hanson, 1984). Moreover, the ‘configuration’ of space is suggested to be the key to a successful design emphasising on the impact of each spatial component to the whole network of the system (Hillier, 1998). From an analytical perspective, it is suggested that in order for an urban layout to be successful in generating ‘life’ it needs to consist of a field of potential encounter and co-presence that support integration and intelligibility (Hillier et al., 1987). This idea suggests that movement in a built environment is mainly supported by spatial configuration, and therefore primarily should be analysed through the existing or proposed urban layout to predict potential ‘life’ in the public realm. In that respect, Space syntax models, formed of self-explanatory, clarified spatial representations propose a simple and quick way to test design proposals.

The lack of current public transport infrastructure and its dependency on car use makes the city difficult to provide necessary conditions for a new proposed public transport system. As the city has grown rapidly outside the historic core through large and continuous highways, the biggest challenge is to make the new public transport system work efficiently through stitching the disconnected parts in order to integrate stations within their contexts. This, in the micro level can be mainly achieved by creating more walkable spaces that can support diverse pedestrian
activities. Gehl (2011) describes walking as a type of transportation as well as ‘an informal and uncomplicated possibility for being present in the public environment’. This is not only crucial to enable accessibility to and from the stations but also to enhance the surroundings by providing potential movement that can support sustainability and improve future land use economy. This approach has been adapted to this study by measuring potential movement patterns through the space syntax agent-based modelling developed by Alasdair Turner et al. at UCL focusing on the relationship between the lines of vision and pedestrian movement. The studies have shown that there is a high correlation between the agents’ analysis and pedestrian behaviour in urban and building scales (Turner, A., 2007). Furthermore, previous findings on agent-based analysis suggest that human movement is highly related to the current location and orientation within the larger environmental system where a long distance vision and well-structured linear arrangement play a big role (Penn A., Turner A., 2002).

Creating walkability in areas where there is lack of pavements and open spaces in addition to hot temperature climatic conditions has been a major challenge throughout the study. Other challenges included a short program, limitation on data availability and the pressure on providing quick response to the design team. However, using an analytical method for grouping station prototypes under a limited number of categories enabled giving quick design feedbacks and main guidelines developed through evidence based approach unique to station locations.

Overall, the main purpose of this study was to integrate stations within their wider contexts focusing on the existing spatial conditions around the sites. This is provided in micro scale level study by analysing immediate surroundings of the station entrances in order to create ease of orientation through an improved wayfinding strategy. Also, the results informed landscape design team in order to optimise potential movement patterns and improve the overall pedestrian friendly approach in the city. The quick iterative feedback to the design team and interactive collaboration enabled this analytical technique to be applied as a guideline throughout the project providing immediate design responses to development process.

2. METHODOLOGY

In order to simplify the process of design and implementation, a set of prototype stations has been identified during the studies carried out by the consultancy and architectural teams defining vertical and horizontal rail alignments and station locations. For each location a specific station prototype has been assigned and as a result, up to nine variations have been developed as a base around the architectural designs to progress. In order to provide feedback on the developing design process, Space Syntax methodology has been used to test the prototype station placement and its effects on urban integration and interaction with surrounding public realm. The methodology consists of two stages: firstly, deciding the locations of architectural prototypes to test and secondly micro scale level agent based analysis of the selected station locations.

2.1 FILTERING ARCHITECTURAL PROTOTYPES

The first step concentrated on creating an output to select the locations that are the most useful test cases to shape prototype stations. Limiting the number of locations to perform spatial analysis helped creating a practical framework enabling a quick process of responding to the design development. In that respect, a station profiling strategy is developed measuring urban characteristics around all stations in order to identify groups of potential locations. Profiling the city, nine locations have been identified to carry out spatial analysis.

The principles of the filtering process considered a wide range of physical conditions that existed across the city from completely vacant land to intensely developed areas. Current highway infrastructure condition is also taken into account in order to respond to station allocations on different levels. The key performance criteria of prototype stations are formed around the idea that they can be applied in a range of physical urban conditions. To ensure that stations will work in all locations, the principle is based on testing them in the most physically constrained areas. In that case, if prototypes are developed within these constraints, they are assumed to work also in less constrained areas such as vacant sites.
The prototype station selection process is achieved through three filtering stages where each filter consisted of a specific aspect of the urban character. The first filtering condition was whether stations were located within town and multi-district centres due to the fact that these areas are where major future growth is proposed. This strategy enabled capturing the areas with future concentration of population and employment growth at the most accessible points to reduce pressure on the road networks. Therefore, developing prototypes that support the pedestrian activity within these centres and creating suitable public realm characteristics is considered to be vital. For the identification of station locations in these centres, Area Action Plans including future restrictions were used prepared by the consultancy team. As a result, 17 stations were filtered among the total 72 stations. The second filtering system included identifying station locations based on their range of existing highway infrastructure conditions. Throughout the city, in multiple areas highway intersections have been separated vertically to improve traffic flows. This has exacerbated issues of severance for pedestrians, while also creating difficult physical conditions for rail infrastructure to adapt. Therefore all stations have been categorised according to whether they were allocated on highway infrastructure at one, two or three levels. Out of the selected 17 stations, 11 had one, three stations had two and the last three stations had three levels of highway infrastructures. Lastly, the stations were filtered based on the spatial accessibility and the level of development around their surroundings. This was identified based on the assumption that the more developed areas would create more physical restriction to respond than less developed or vacant lands. A measure combining the pedestrian network with the level of development has been prepared through the spatial accessibility model and the land use data. At the conclusion of the final ranking process, a set of potential prototype locations has been identified. The diagram below illustrates the filtering process of the architectural prototypes (Fig. 1).
Figure 1 - Filtering process of the station prototypes
2.2 ORIGIN DESTINATION WEIGHTED AGENT BASED MODELLING

Following the filtering system of the station prototypes, the final selected 9 stations have been tested through micro scale agent analysis. The purpose of this analysis was to develop a methodology that could be replicated for other prototypes and their test locations. The principles of the analysis included providing suggestions to improve wayfinding quality of station exits such that the generated movement patterns would complement the proposed urban context. Moreover, in order to integrate stations within their contexts the station entrances are suggested to be visible and easily accessible to users and easy for pedestrians to orient themselves within the city from the point they exit the stations. Positioning of street furniture, shading effect and public realm quality were also analysed in relation to potential movement patterns.

The agent models were weighted by origins and destinations in order to predict patterns of movement that the design options would generate. This approach has been previously adapted through assigning long distance vision and specific behaviours to agents (Penn and Turner, 2003). In the origin-destination model, agents are programmed to move between certain points in a defined space; navigating through the space on the basis of what they can see at each point in space and deciding the direction of their next steps at every several steps. Once the agents enter a space, they choose the route that is easiest to navigate through and also that takes them nearer to destination (Ferguson et al., 2012). The final visuals of agent analysis represent the movement density in form of path overlaps where the higher movement density is represented by warm colours. Overall, for the number of people used in agent analysis was taken from the ridership figures developed by international planning and transport consultants.

However, in the absence of data, four assumptions were made based on prior research on the existing land use, density and movement conditions in the city:

a. Taxi drop-offs are estimated to accommodate 20% of the origin and destination movement.

b. Major land use attractors such as shopping malls, hospital, juma mosques and universities involve 30% of the origin and destination movement.

c. Public realm attracts the rest of the origin and destination movement distribution. If the station area lacks of any major land use attractors, 80% of the movement would be distributed to the surrounding street network based on their spatial accessibility.

d. Light Rail Transit (LRT) attracts the percentage of movement obtained from the ridership figures based on its capacity and estimated use.

The movement patterns in agent analysis were tested against two components: ‘spatial configuration’ and ‘land use attractors’. In that regard, ‘configuration’ is suggested to create ‘through-movement’, whereas land use attractors generate ‘to movement’ (Hillier et al., 1993). The relation between ‘attraction’, ‘configuration’ and ‘movement’ is further described as: “... movement is seen as being ‘to’ and ‘from’ built forms with differing degrees of attraction, and design is seen as coping with the local consequences of that attraction” (Hillier et al., 1993). The assumptions above represent the origin-destination based ‘to’ movement generated by land use attractors, whereas ‘through’ movement is tested along the spatial configuration using the spatial accessibility values of the public realm. Three layers of movement were tested in agent analysis: ‘from’, ‘to’ and ‘background’ movements which were then combined as all forms of movement attraction are argued to be interrelated (Griffiths et al., 2008). Firstly, the movement ‘from’ stations was tested by releasing agents from the station exits which moved to defined destinations such as taxi drop-offs as well as land use attractors including mosques, retail units and offices. Secondly, the reverse movement was analysed where all agents were directed ‘to’ station entrances. Thirdly, the background flow around the surrounding public realm was included where the highest spatial accessibility values of spatial model were used to distribute agent movement. Furthermore, climatic conditions have also been considered by weighting agent models with shaded areas aligned with day and night time scenarios.

1 Due to the confidentiality issues, the name of these companies or further references cannot be revealed.
Overall, Origin-Destination distribution assumptions were used to demonstrate how pedestrian movement could occur in real time scenarios based on the modal split, the land use of the surrounding context and the spatial accessibility of the public realm.

Finally, the results were used to produce opportunities and constraints principles identifying connections, open space location, key desire lines, frontage and interface characteristics. Iterative design feedbacks and guidelines have been provided to the design team by modelling further proposal iterations, testing and feeding back results through diagrams and workshops. Also, the results were reviewed against predefined design principles that facilitate movement around the stations while providing quality public realm. In order to ensure the adequate flow of station users and background movement while keeping land acquisition to a minimum, pavement widths were analysed around station placements (Fig.2). Using ridership figures per station location with Level of Service standards used by TfL (2010), the minimum land requirement was calculated and shared with the adaptation and landscape teams. This enabled defining the capacity of space needed around stations with the aim of minimising cost. The iterative process has been achieved working closely with architects and giving feedback on weekly workshops that helped developing new versions of design for each station. The outcomes of new designs have been tested focusing on the way in which agents moved through spaces. However, this paper will not focus on the detailed technical methodology of agent based modelling, instead, it will concentrate on the design feedback process reflecting on two selected stations as case studies.

3. ANALYSIS

3.1 STATION A

Station A is located within the oldest part of the city within an organically developed layout. Despite being situated at the heart of the city and within a close proximity to local pedestrian infrastructure, the main station entrance is located at the centre of a high-speed traffic roundabout with the lack of traffic lights as well as grade level pedestrian crossings. It also sits at the intersection of differing urban structures and land uses. The dense urban grain of the historic core interfaces with large block structure to the north and the lagoon and recreational green spaces to the west. Therefore, the station design and placement is an opportunity to weave these elements together and support a public realm that is conducive for movement. Moreover, it includes the potential to address urban severance by providing spatial conditions.
to link across infrastructure. This would provide a major benefit to the existing population regardless of whether if they use the station. Therefore, the brief requires responding to the current station design in a way that it could integrate with the wider surrounding context through the identified key desire lines (Fig. 3). Also, the historical importance of its location and the proximity to one of the oldest landmarks gives it a symbolic mission to create a visual connection and accessibility with the historic core of the city.

The main tasks of the Station A were:

a. Overcoming severance between the station and its context caused by the lack of pedestrian crossings, bridges and underpasses around the roundabout.

b. Developing a legible design for the station exit/entry to ease way finding for the pedestrians.

Due to the traffic speed and technical regulations, the number of potential crossings that can be provided at grade level was limited. Collaborating with the design team, a single large shared surface to the south of the roundabout has been proposed in order to provide access between the station and the historic core. In the meantime, in order to restrict informal crossings at grade level, a pedestrian underpass design has been developed on the western end of the roundabout that connects the station to the lagoon bridge as well as the mosque. The proposed design firstly has been tested by movement of agents leaving the station and distributed towards the public realm.
The initial experiment focused on the analysis of the underpass use, observing whether the agents would take the underpass to cross the street or if they would take the existing informal crossings around the medians. The main purpose of this testing was to find the ideal scenario where the use of informal crossings would be minimised. The analysis of the current proposed design has shown that the underpass is likely to be only used by people visiting the mosque and not crossing the lagoon. The result of this is that the lower level space will be underused for much of its time, and will not create an active piece of public realm. Also, the current design is compromised by the width and angle of the staircases. These make it difficult find, and may become crowded when they are used at peak times. In that respect, alongside with the current design two alternative options have been tested (Fig.5).

Figure 4 – Origin (in blue), Destination (in red), Distribution and Agent Analysis of the proposed design

Figure 5 – Analysis of three options for the proposed underpass design (from left to right): The current proposed design, Widened entrance option, At grade level crossing option
The first option retains the tunnel, but opens up the entrance to make it visible from a wider area and the second option proposes a crossing at grade to see whether this attracts more people to move through it than the tunnel. The findings of these tests suggest that the underpass should be widened, shifted to the south slightly, and that the two stairs at the entrance from the lagoon should be widened and turned into a single large stair.

The second analysis focused on the spatial positioning and thus effectiveness of the secondary eastern entrance to facilitate movement to and around the station. In that regard, three options were tested to observe pedestrian movement patterns generated by the proposed design options: Multi-directional exit, Historic core facing exit, Drop-off area facing exit (Fig. 6).

The results have been evaluated under five criteria:

a. Wayfinding and orientation with the historic core
b. Quality of arrival space and Level of Service
c. Minimisation of movement congestion at east exit
d. Minimisation of below grade disorientation toward east exit
e. Reduction of movement pressure from Central stairway from grade to concourse level

The findings have shown that the first scenario with multi-directional exit works better than the other two options. The escalator positioning allows for passengers to view the historic core, drop-off areas and north crossing upon exit. The provision of space in front provides good level of service for movement. It also proposes a good opportunity for quality public realm and landscaping to facilitate movement toward surrounding destinations. On the other hand, the option 2 allows for exiting passengers to face historic core, however, movement toward the north crossing and drop-off areas are visually blocked. Also, the indirect movement caused by below grade angle-change holds the potential to cause congestion leaving the station. Lastly, the third option facing the drop-off area creates a visual block to the historic core where also the multi-directional movement in front of the exit has the potential to cause congestion.

Further analysis has been carried out of the latest design to see how placement and sizing of stairs affects urban integration. Recommendations have been made to show how the placement of stairs could be improved. In order to improve agent movement scenarios with a finer grain assessment, environmental survey studies have also been included in the agent based modelling. Considering the average thermal comfort levels against exposed hot conditions, 'Day' and 'Night' time scenarios have been tested to show the impact of climatic responses to proposed design (Fig. 7). The agent model in the 'Day' scenario has been weighted with the assumption that the shaded areas around the station concourse would attract 80% of the movement whereas, the 'Night' scenario assumes that the movement will be unaffected by the shading provision where agents will move freely. The results have shown that, in the 'Day' scenario the movement on the underpass and the eastern escalators are higher than in the central staircases. Also, due to its strong visual connection and spatial accessibility the eastern
turnstile area is more likely to attract potential movement. Therefore, it needs a detailed design assessment that responds to any potential for future congestion. On the other hand, ‘Night’ scenario testing has shown that, the eastern staircase of the central link to the historic core may lead to potential congestion due to the fact that the western stair access is blocked by the proposed landscape design. As a result, the central staircases are suggested for further reshaping to ease movement between the historic core and the station.

Figure 7 - Agent analysis of the ‘Day’ and ‘Night’ scenarios

3.2 STATION B

Station B is planned in a more recently grown part of the city and located in the middle of a highway infrastructure and within a close proximity to a shopping mall. It also requires a link to a Light Rail Transit (LRT) station where a high percentage of interchange movement assumption was included in between both entrances. Analysis has focused to explore entry placement and landscape response to the station integration with the surrounding. An important element of the analysis was to consider the link between the LRT and MRT stations where at peak times the ridership figures for interchange movement accounted for 80% of the station related movement. The high potential of movement within and around the station led to a detailed analysis of the existing condition around the site as well as defining the key pedestrian desire lines (Fig. 8).

The main tasks of the Station B were:

a. Overcoming the challenges in existing condition caused by the lack of pavements, high-speed traffic and pedestrian crossings.

b. Creating a link between the existing and future developments while developing a legible design for the station exit/entry to ease way finding for the pedestrians.

c. Creating a legible route between LRT and MRT stations that supports proposed retail units within the MRT station.
The main challenge for the design development of Station B was adapting the proposed design to an existing context that lacked pedestrian infrastructure. In the current condition, with the absence of pavements, pedestrians are forced to walk through the existing car parking for the mall in order to access public realm on the west. In addition, the lack of pedestrian crossings, enforce pedestrians to cross the highway informally. In order for station to work optimally, it requires integration into its urban structure in a way that is conducive for access, use and comfort. Retail, green space and other land uses would also need to work together with the station to function effectively. In order for station entrances to work legible for pedestrians, crossings should be provided on key desire lines at grade level. However, due to the traffic regulations around the site no new crossings could be added to the current context. Therefore, the proposed design included a raised pedestrian bridge that connects east and west over the MRT station. The analyses consisted of testing the existing formal and informal crossings, the proposed pedestrian bridge and the proposed route between the MRT and LRT stations. The assumptions were made of two types of pedestrian movement: the interchange movement between the MRT and LRT and the movement in and around the urban area including ‘to’ and ‘from’ the stations.

The initial analysis has compared the impact of recommended design iterations by testing the existing and recommended options. The results have shown that, current crossings are not aligned with the desire lines between the entrances of MRT and LRT stations. The image below represents how changing the current widths and the locations of existing crossings (1 and 2) can improve the potential pedestrian movement between the two stations (Fig.9).
In the current proposed design, due to the narrow width and the angular change in crossing 1, the main movement between the station entrances are attracted towards the western escalators. In the recommended option, by creating a larger shared crossing on the desire line, it is possible to reduce the number of crossings on the highways. Being located on the desire line with a high potential of background movement, this widened crossing has also a potential to support movement in the wider area. Also, the removal of other crossings from the highway concentrates the main movement pattern on the central area where new retail units are proposed. This does not only support retail activity but also takes the pressure off the pedestrian bridge. Thus, during the peak times, it needs to support approximately 5,000 people per hour. In order to make sense of this data, it can be compared to a previous study where it shows the number of people per hour in New Oxford Street as only 1,190 during the PM Peak. (Space Syntax Limited, 2014).

Further studies included testing two other options both without the pedestrian bridge and one where the entrance is flipped. Then, the results have been compared by three criteria: distance between MRT and LRT, number of at grade level crossings with high pedestrian flow and the reduction in potential land take. The first option shows that, the removal of the bridge requires a grade level crossing (2) between the MRT and the Mall location. This crossing will be used more for MRT to Mall movement, whereas MRT to LRT will mainly rely on the wide at-grade crossing (1). The southern entrance will allow greater access to retail units as generated by station users moving toward or coming from LRT interchange. The distance between MRT and LRT stations in the first option is 390 metres. The number of grade crossings with high pedestrian flow is 4. The second option provides the closest proximity between the MRT and LRT stations by 270 metres. The MRT entry to the north has clear line-of-sight through the wide grade crossing provision (1) to connect the MRT and LRT stations. However, this option creates a challenge to support retail, but it does create an opportunity to add missing community infrastructure. The number of grade crossings with high pedestrian flow decreases to 3. Both options allow for reductions in potential land take areas by 2,910 square meters compared to the first option with the pedestrian bridge. All these option analyses provide different scenarios and urban impacts to consider during the design development process.
4. DISCUSSION AND CONCLUSION

The analyses have shown the ways in which an evidence-based analytical study can contribute to a real time architectural project through continuous feedbacks by providing strategic design guidelines. The two case studies reflected diverse design iteration processes differing from each other by spatial as well as historical contexts. Each case study required a unique analytical approach to prepare guidelines for equivalent prototype stations. The guidelines for the station design were mainly formed around improving the quality of public realm as well as supporting proposed land use for future developments. This has been enhanced in the micro scale level by providing simple interface for users to find the station entrances and ease of orientation within the city upon leaving the stations. The options were tested through agent based modelling where origin and destination assumptions were made based on ridership figures, land use attractors and the spatial accessibility around the stations. The results of the analyses showed potential patterns of movement generated by proposed design options that are reviewed against desired guidelines in order to inform the architectural team on regular weekly workshops.

The study consisted major challenges throughout the working process. The first challenge was to accommodate proposed design to a context that lacked existing pedestrian infrastructure where the absence of pavements and crossings created constraints in creating walkable spaces around the stations. Secondly, the limitation of data availability made it difficult to test the design options by real figures. Instead, assumptions were created estimating the proportional distribution of agents for each destination where ridership figures did not include taxi-drop offs and land use attractors. Therefore, this methodology was tested on different scenarios to consider a variety of possibilities. Thirdly, hot temperature climatic conditions created challenges in enhancing the design of pedestrian activity in open spaces. This required additional considerations for design strategy to focus in creating comfortable environment for the use of public realm. In addition, agent based analysis remained inadequate in responding to certain aspects such as exact figures for potential congestion and movement density. Instead of quantifiable measures, agent based modelling helped defining the spaces for potential movement density that enabled proposing unique design responses to these challenges.

The study consisted of responding to existing difficulties through a variety of methodological decisions. In order to overcome the constraints caused by missing pedestrian infrastructure, each design option has been tested in a way that they could improve the current public realm conditions as well as enhancing future proposed designs. This has been enabled through the testing of background movement based on spatial accessibility levels on the existing public realm.
realm. Combining three types of movements including ‘to’ the station, ‘from’ the station and background movements allowed overlapping the existing and future predicted movement patterns. This gave an opportunity to test all potential movement patterns at the same time frame. Also, in order to understand the impact of climatic conditions on movement patterns and to decide on the allocation of shading elements, the analysis consisted of testing ‘Day’ and ‘Night’ time scenarios of proposed designs. This also enabled identifying areas with high risk of congestion due to shaded areas being chosen by the majority of agents where different design approaches can be adapted. Moreover, in the absence of concrete data on estimated numbers of movement, the assumptions in this study formed an adaptable and flexible methodology that could be replicated to prototypical case studies in order to provide quick responses to the design team testing various scenarios.

Overall, despite the limitations during the design development process, the adaptation of the space syntax methodology to test a large number of stations enabled a systematic, quantifiable approach for the basis of multiple case studies. The contextualising process of stations gave the benefit of time efficiency on planning multiple architectural prototypes. In addition, agent based modelling provided a fine grain study for each design option and to develop further design decisions. One of the benefits of agent-based analysis was to understand the issues where the internal wayfinding wasn’t integrated within the context. In this case, the results were used to improve current spatial conditions as well as future proposed design options. Agents were also helpful in identifying the lack of current pedestrian infrastructure through adapting the proposed design to existing context with lack of pavements or crossings. This allowed for specific issues to be addressed during the design development process through precise option testing of proposed designs. Agent based modelling also allowed testing the proposed designs in a precise way considering exact widths of crossings and proposed pedestrian bridges as well as underpasses. Also, the quantification of the movement patterns in certain areas allowed communicating the impact of design options to architects through benchmarking of previous precedent studies. Lastly, this study has shown the potentials of creating quick iterative design feedbacks on an architectural project reflecting on the collaboration between academia and practice.
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ABSTRACT
Natural movement is defined as the pedestrian movement potentially generated by the configuration of the street network irrespective of any other factors (Hillier et al 1993). The structure of the urban fabric is considered to be the primary generator of movement, although attractors such as specific ‘land uses’ for example, might also act as factors in generating additional movement. Traditional shops along a high street build upon the potential provided by natural movement. Conversely, the concept of shopping malls is to create attraction through concentrated land-uses (retail density) allied to car accessibility (regardless of pedestrian accessibility). The spatial juxtaposition of these two retail models therefore challenges the way the syntactic structure of the street operates, resulting in multiple frontages and points of access that may pose conflicting demands and a sense of disorientation.

The case study is a shopping mall located in the Newcastle City Centre, bordered on one side by the high street and on another by one of the main city squares. This ‘hybrid’ building has developed its own circulation system: it is publicly accessible but privately owned, which implies restricted accessibility over the course of the day and week. As such, accessibility is re-evaluated depending upon the nature of the internal open space (privately owned but, at times, publically accessible). Accessibility is measured at the city scale, and the neighbourhood scale inclusive and exclusive of the internal open space. It is also assessed by the volume of shoppers entering the shopping mall’s 20 separate entrances and is linked back to the syntactic structure of the streets. Finally, the impact of movement generated by street structure on retail located in the shopping mall is analysed through the layout of a department store that fronts both the shopping mall (internal frontage) while having also maintained its traditional frontage onto the high street (external frontage).

KEYWORDS
frontage, retail, shopping centre, high street, natural movement
1. INTRODUCTION

Frontage is the place where public and private domains meet. It participates in both the definition of a building façade and the definition of a street elevation. It creates potential exposure of a privately own space to the public at large and it is used by real estate agencies to assess the value of land (commercial in particular, taxation). It is where one accesses a property. Some urban forms have dematerialised the frontage (suburban setbacks or modernist housing estate) and even in certain cases privatised and internalized it (shopping mall).

This paper will look at the implications of internalised frontages in a traditional urban fabric, more specifically, their impact on movement. In the case of retail, the internalisation of frontages within a shopping centre model fully disregards the external frontage of the building. This internalisation is made explicit in the dumb-bell configuration pioneered by architect–planner Victor Gruen (1960). The dumb-bell plan is designed to minimize the distance between anchor stores (Maitland 1990), to maximize and evenly distribute movement, therefore exposure to all the shops (Jewell 2001). It is based on the principle of the high street with shops on each side of the street capped with an anchor store at each end (figure 01-c). By terminating the main thoroughfare at major shops, the model concentrates all its circulation to the centre and minimizes pedestrian traffic on the periphery. The location of attractors such as anchor stores in the layout of a shopping centre plays a strong role in equalizing pedestrian traffic throughout its main central circulation (Fong 2003). As an introverted building type, the shopping mall doesn’t relate to its site, but capitalizes on the parking areas and access to arterial roads and motorways. The entrances of a traditional shopping centre are generally not highly visible and often through the entrances of the anchor stores.

On the opposite spectrum of the retail model, the ‘live centres’ of cities are the places where activities, exchanges and interactions take place in a more intense manner. It is characterised by a higher density of people and frequency of movement. The High street (figure 01-a) is often the focus of live centres with a high concentration of shops, activities and entertainment that benefit from its central location within the city fabric (Hillier 1999, Scoppa and Peponis 2015). In other words, there is a natural exchange of benefits between the economic activities and the configuration of the street network. However, the street network both generates and restricts its potential for traffic through its sole spatial configuration (depending on how availability of streets and connections). The High street generates through movement and exemplifies the ‘movement economy’ within cites which is “the reciprocal effect of space and movement onto each other to which is added the multiplier effect of land-use and building density” (Hillier 1996).
2. INTU ELDON SQUARE: A SHOPPING MALL ON A HIGH STREET

The construction of a shopping centre next to the traditional High street intensifies the density of movement whilst establishing a tension between shops located within the shopping centre and those located along the High street. Since the space allocated to parking is minimised, alternative sources for shoppers are sought. A previous study looked at an enclosed shopping mall in a Downtown area in the US and questioned the benefits the shopping centre brought to the surrounding conventional shopping streets, finding the internal frontages to be more successful in attaining pedestrian numbers whilst limiting the spread to the outside (Lorch & Smith 93).

Both models follow opposed modes of operation: the high street provides natural movement via its central and integrated location within the city centre upon which retail builds, while the shopping centre is designed to attract shoppers with ease of access (car + parking) and then to contain all movement within its precincts. By locating a shopping centre within a city centre, the shopping centre loses ease of access and attempts to capitalise upon the potential created by the natural movement of city centres.

Shopping centre embedded within the urban fabric of a city centre is a fairly common one in the UK. With the exception of Sheffield, which boasts an open air shopping area (Orchad centre), each major city in the UK now has an enclosed shopping centre within its centre. Out of the 40 largest shopping centres in the UK, 15 are located within the city centre, 10 are fully
suburban (i.e. out of town and surrounding by parking areas) and 15 can be considered as mixed (with a looser fabric, often creating new cities). They could be described respectively as the ‘Major Urban Centre’ type, the ‘Regional’ type and the ‘Urban Centre’ type. This paper uses the example of Intu Eldon Square, a shopping centre embedded within the city centre of Newcastle, which falls in the category of ‘Major Urban Centre’. It ranks 13th in terms of size in the UK and is located less than 5 miles away from the largest shopping centre in the UK – the Regional Metrocentre in Gateshead. Intu Eldon Square has been constructing in multiple stages using two existing anchor stores (flagship stores) located on the high street and the relocation of another. It opened in 1977 and is owned by joint venture by Newcastle City Council (40%) and Intu (60%). A later phase added another shopping centre ‘Eldon Garden’ onto the west side, thus expanding its total footprint. The latest development was the addition of an anchor store on its southern part in 2004 (figure 02-c) and the refurbishment of a new food court near Monument in 2016. The development destroyed a major part of the city centre and redesigned parts of a main square renamed ‘Old Eldon Square’ (figure 02-a). According to Maitland’s main categorisation of shopping mall layouts, it can be assimilated to the L shaped type (Maitland 1985).

The introduction of the shopping centre into the city fabric and the destruction (or internalisation) of existing streets is assessed by evaluating the impact at differing scales. The relationship of the high street and the shopping centre is looked at the scale of the city, the shopping centre and the shop. Firstly, and at the city scale, the paper concentrates on the effect of the assimilation of internal circulation to the public space and street network (global properties of the grid). It compares the syntactical core of the high street model with that of the shopping centre, as two independent systems, and their affect upon each other when combined into a single system. Based on this observation, the corridor and High street systems are compared. The second part focuses on the accessibility of the shopping centre itself and how it relates to the surrounding street and in particular, the High street. Accessibility is assessed as the volume of shoppers, or footfall, passing through the various entrances of the shopping centre and the location of these entrances is evaluated against the surrounding streets, with emerging configurations highlighted. Finally, to clarify and distinguish the impact of both models, the paper examines the anchor stores of the shopping centre, with each having a different relationship to the internal corridor and the external street: one has an internal frontage only and is fully dependent on the shopping centre and its carpark, the second is equally accessible from the street and from the internal corridor of the shopping centre, and finally a traditional department store on the High street with internal access to the shopping centre as well as multiple accesses and frontages on other streets. This last model also clarifies the distribution of movement at the level of frontage for a single shop.

1 As defined by Costar.UK: ‘Major urban centre’: Shopping Centres in large towns and cities. ‘Regional’: Large, dominant regional shopping centres in out of town locations, covering a large catchment and which are the leading shopping destinations for those with cars. ‘Urban Centre’: Shopping Centres in smaller towns and suburbs.
3. INTERNALIZING PUBLIC SPACE

How does the internal circulations of a shopping centre impact upon its surrounding streets and most importantly the existing High street? Is there a shift from an outdoor core to an indoor core by adding more streets to the system? Is there an increased or decreased integration?

In order to understand the impact of internal circulation on the natural movement of the city centre, three axial maps are drawn to represent: the city centre, the shopping centre and its peripheral streets and finally the city centre with the internal circulation of the shopping centre. The city centre axial map (figure 03-b) is drawn from a pedestrian point of view, and as such includes elevated pathways, reminiscence of the 1960s urbanism and pedestrian paths through the two university campuses. The limits of the map follow existing boundaries that prohibit or make walking connections uneasy: on the north, the motorway and the town moor; on the east, the motorway; on the south, the topography and the railway; and on the west, the stadium and boulevards. The city centre has been greatly pedestrianised and restricted access has been given to bus and taxi traffic; the city established a shared surface system.

The shopping centre axial map (figure 03-a) includes the internal circulation that is accessible directly from the street or public space. Circulation is distributed on three floors; the main floor which is at the entrance level on the High street (Northumberland Street); the lower floor which is at the level of Old Eldon Square Garden and the Upper floor, which is not directly accessible from the outside with limited circulation (Eldon Garden) and has been omitted from the map for legibility. Vertical circulation is included in the axial map through either a sets of lines (stairs) or a single line (escalators) and elevators are excluded. Finally, the streets surrounding the shopping centre are included since they participate in the accessibility of the shopping centre and support its street frontage. They are extracted from the city centre axial map.

The third map is the combination of the city centre and shopping centre maps into a single study (figure 03-c). Each of these maps represent a different perception of the city. The movement throughout the city when all shops are closed is represented in the city centre map. During opening hours, all accessible spaces are represented through the combination of the shopping centre and city maps. The shopping centre map is a proxy for the shopping experience as though the building was located within a suburban environment surrounded by parking lots; while the addition of the city centre streets represents its urban condition.
The analysis of the map using depthmapX computes the integration [HH] values for each line. The mean integration values for each map is reported in Table 02. It shows that the shopping centre as an independent system has the overall higher integration, indicating that all spaces are in close proximity to each other. The design of the shopping centre aims to maximise its central circulation and to limit circulation at its periphery. On the other hand, the city centre benefits from the shopping centre that increases its overall integration by 5.5 percent (from (b) to (c)). When embedded into the city centre fabric, the shopping centre loses in overall integration by -5.6 percent (from (a) to (b)).

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean Integration</th>
<th>Diff.</th>
<th>n</th>
<th>Mean integration (isolated)</th>
<th>Mean integration (embedded)</th>
<th>Diff.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shopping centre (a)</td>
<td>110</td>
<td>1.404</td>
<td>-5.6%</td>
<td>5</td>
<td>1.99</td>
<td>1.54</td>
<td>-22.78%</td>
</tr>
<tr>
<td>City centre (b)</td>
<td>375</td>
<td>1.256</td>
<td></td>
<td>18</td>
<td>1.92</td>
<td>2.04</td>
<td>+6.01%</td>
</tr>
<tr>
<td>City centre + shopping centre (c)</td>
<td>467</td>
<td>1.325</td>
<td>+5.5%</td>
<td>23</td>
<td>1.99</td>
<td>1.99</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Table 2 - mean integration values for each axial map, and for the integration cores (top 5%). The increase and decrease of mean value when the shopping centre is embedded in the city centre.
Figure 3 - on the left: axial maps of Integration [HH]: red for the most integrated and blue for the least integrated values. On the right: the integration cores (top 5% and 10%) for the shopping centre and the peripheral streets (a) the city centre without the shopping centre (b) and with the shopping centre (c).
Looking at the integration cores (Hillier and Hanson, 1984), the same set of axial lines that form the integration core (top 5%) of the shopping mall decreases by almost a quarter of its value (-23%) when embedded into the city centre street network. By opposition the set of axial lines that forms the integration core of the city centre without the shopping centre increases by 6 percent when it is included.

The syntactic core of the city centre doesn’t shift with the introduction of the shopping centre but benefits from the internal circulation that increases its integration core by 6 percent, and the city centre overall by 5.5 percent. When thought of as an independent system that is disconnected from the larger context but includes the streets that run along its periphery, the shopping centre has its integration core located upon the upper level corridor linking two anchor stores and expands to its lower level and onto a major street. That major street running east-west, Blackett street, is common to all the integration cores with the 3 maps.

4. CORRIDOR AND HIGH STREET

Can the internal circulation be assimilated to a high street? As a closed system, the shopping centre has a more integrated system overall with its most integrated street being the corridor that links the two main anchors. The high street is located on the opposite side of the most integrated corridor. They are however on the same grade and are at least 4 steps away from each other. The high street, syntactically defined by Hillier (1999), has a very particular form and tends to produce a local intensification of the grid. In this case, the size of the shopping centre itself denies any fragmentation on the west side of the High street. The number of intersecting streets on the west of the upper part of the high street (Northumberland street) is very low compared to its lower part (Pilgrim street). As illustrated in figure 01, the surface taken by the shopping mall has removed all the existing lanes and back alleys that made this part of the city more connected (House and Fullerton 1955). Furthermore, the intensification of the grid is prevented by the syntactic structure of the shopping centre which minimises connections at the periphery. Figure 04 shows the difference between the High street and the most integrated corridor of the shopping centre in terms of available spaces that are located one step (red) and two steps (black) away from the corridor. The 2 steps away structure considers the High street and the main corridor as points of departure and shows the amount of space available when changing direction twice.
Only one direct connection is made between the high street and the shopping centre. Within the 2 steps away structure only two others spaces are picked forming a Y shape inside the shopping centre (figure 4-a – dotted lines). These three segments are not penetrating deep inside the shopping mall and remains very much at its periphery. Similarly, the structure of the shopping centre, from the most integrated corridor, shows that its location is deep inside the building (figure 03-b) with one connection to the outside linking it to a public square (Old Eldon Square), off the main road (Blackett street).

Similar disconnections to the surrounding main roads were observed in a Dutch shopping mall (Teklenburg, Borgers et al. 1994). The weakness of the relationship between the High street and the shopping mall is already present in the design of the shopping centre, as first implemented in 1976. Interestingly the connection is not perpendicular to the High street but in the diagonal. There is a double connection that is perpendicular to the high street, following the existing lane (Prudhoe charle), but the door is located at its terminal rather than aligned with the High street, creating a corner condition for the diagonal entrance. It could be hypothesized that the high
street acts as an anchor store and caps the north-east end of the shopping centre. As such, the diagonal is designed to minimize the distance between the anchor stores' internal entrances and the anchor 'high street' entrance.

5. ACCESS STRATEGIES

Syntactically it has been observed that the High street and the shopping centre follow two distinctive configurations and that their adjacency doesn't necessarily mean that they are well connected. The impact of their spatial proximity with minimum connections is tested through examination of the 'popularity' of the shopping mall entrances. Despite their minimal direct connection, does the shopping centre depend or profit from the natural movement generated by the High street? What are the alternatives for the shopping centre?

The 'popularity' of these two modes of retail can be assessed by the volume of pedestrians that pass through the entrances (exits) of the shopping centre, its footfall. The location of these entrances will show which surrounding streets bring shoppers in and out of the shopping centre. The 20 entrances of the shopping centre can be classified into three types: 7 street level entrances (direct access from street), 10 elevated entrances (stairs or escalator linked to the street) and 3 internal entrances (from the inside of the shopping centre or connected to parking deck). Within this collection of data, entrances through shops are excluded (12 or more) as well as services entrances. All observed entrances are mapped in figure 05.

The volume of pedestrians is an average of multiple observations made over 2 Saturdays between 11h00 and 15h00, and one Thursday between 16h00 and 18h00. Observations were made by counting the number of pedestrians entering and exiting for 5 minutes at each entrance with a total number of people per minute being provided for each entrance. Table 03 shows that direct entrances from the street provide the largest volume of people, followed by the elevated entrances and the internal entrances linked to parking decks. The elevated entrances tend to be used more as exits rather than entrances, which can be easily explained by the effort required to ascend stairs to access the main floor from the street.

2 Pedestrian counts were recorded with the help of Master and Phd Students: Yick Fong, Alex Furniss, Yuk Ting Lee, Daniel Rush, Dr. Kyung Seo, Melissa Tang, and Agnieszka Wir-konas.
Figure 5 - location of entrances to the shopping centre, including access through the anchor stores (italic) – graph showing the volumes of shoppers passing through each entrance per minutes.
Table 3 - Volume of people per minutes entering and exiting the shopping centre per type of entrances.

<table>
<thead>
<tr>
<th>Type entrance</th>
<th>n</th>
<th>pp/min average</th>
<th>pp/min IN</th>
<th>pp/min OUT</th>
<th>pp/min TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – street level</td>
<td>7</td>
<td>57.03</td>
<td>213.6</td>
<td>185.6</td>
<td>399.2</td>
</tr>
<tr>
<td>2 – elevated</td>
<td>10</td>
<td>7.22</td>
<td>29.4</td>
<td>42.8</td>
<td>72.2</td>
</tr>
<tr>
<td>3 – internal</td>
<td>3</td>
<td>5.93</td>
<td>9.4</td>
<td>8.4</td>
<td>17.8</td>
</tr>
<tr>
<td>total</td>
<td></td>
<td>252.4</td>
<td>236.8</td>
<td></td>
<td>489.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Street</th>
<th>n</th>
<th>pp/min average</th>
<th>pp/min IN</th>
<th>pp/min OUT</th>
<th>pp/min TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northumberland Street</td>
<td>1</td>
<td>136.2</td>
<td>69.6</td>
<td>66.6</td>
<td>136.2</td>
</tr>
<tr>
<td>Clayton Street</td>
<td>2</td>
<td>50.60</td>
<td>45.8</td>
<td>55.4</td>
<td>101.2</td>
</tr>
<tr>
<td>Old Eldon Square</td>
<td>3</td>
<td>25.27</td>
<td>41</td>
<td>34.8</td>
<td>75.8</td>
</tr>
<tr>
<td>Percy Street</td>
<td>7</td>
<td>8.37</td>
<td>28.6</td>
<td>30</td>
<td>58.6</td>
</tr>
<tr>
<td>Blackett Street</td>
<td>1</td>
<td>51.2</td>
<td>27.2</td>
<td>24</td>
<td>51.2</td>
</tr>
<tr>
<td>Grainger Street</td>
<td>1</td>
<td>43.6</td>
<td>28.4</td>
<td>15.2</td>
<td>43.6</td>
</tr>
<tr>
<td>Morden Street</td>
<td>2</td>
<td>5.6</td>
<td>4.8</td>
<td>6.4</td>
<td>11.2</td>
</tr>
<tr>
<td>Newgate street</td>
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<td>4.4</td>
<td>2.4</td>
<td>2</td>
<td>4.4</td>
</tr>
<tr>
<td>Prudhoe Chare</td>
<td>1</td>
<td>4</td>
<td>2.8</td>
<td>1.2</td>
<td>4</td>
</tr>
<tr>
<td>Prudhoe Place</td>
<td>1</td>
<td>3</td>
<td>1.8</td>
<td>1.2</td>
<td>3</td>
</tr>
</tbody>
</table>

Averaging observations, about 489.2 people per minute passed through the 20 entrances of the shopping centre, either entering (252.4/min) or exiting (236.8pp/min) and can be roughly split in half for each direction. When aggregated by street, the most used streets are Northumberland street, the high street; followed by Clayton street and Old Eldon square, both located on each side of Blackett street. Percy street comes in 4th position capitalising overall on its numerous entrances (7). The second entrance off the high street, on Prudhoe Chare is one of the least used.

If each entrance is taken independently (figure 05-graph), the main entrance of the mall remains on Northumberland street [01] with a capacity of 136.2 pp/min, which is more than the double of the volumes for the 2nd entrance and the 3rd entrances. The other most used entrances, with a volume of pedestrian between 50-60 pp/min [03, 05, 07], create an axis perpendicular to Blackett street and crosses Old Eldon Square. Eldon Garden shopping centre doesn’t perform well overall, with less than 10 pp/min at its busiest entrance [15].

Three strategies for the location of entrances emerge from these observations (figure 06): the first capitalizing on a prominent location i.e. the high street (figure 06-a); the second placing the accesses in a line forming another axis (figure 06-b) and finally another strategy is to multiply the number of entrances along a street on each side (figure 06-c). While these strategies show how the shopping centre relates to the street and capitalizes on pedestrian from the street rather than relying solely on carpark, how do the shops locate themselves towards these two conflicting models?
Figure 6 - Strategies to build upon the street network: high street entrance (a) – alignment of entrances to form an axis (b) and multiplication of entrances (c).
6. FRONTAGE STRATEGIES

The originality of Intu Eldon Square is its use of an existing department store as anchor store. From an urban point of view, the typology of the department store is commonly defined by buildings that occupied entire city blocks. This allowed stores to maximise their presence within the city and to exploit urban situations / street-networks that afforded approach from several different directions with multiple store entrances (Figure 01-b). Fenwick (FW) of Newcastle is something of a typological anomaly. Today the store occupies a city block, however this is a result of incremental growth over time rather than an initial statement of grand ambition. First only facing Northumberland street, it extended its linear facades on the high street, added a frontage on Blackett street, opened an access on the shopping centre and finally connected directly to the metro on its lower level. This building becomes an ideal candidate to understand how the dynamic of the high street cohabits with the dynamic of the shopping centre. It is compared with two other anchor stores: John Lewis (JL) which is located within the shopping centre without any street frontage, fully dependent then on internal pedestrian traffic and carpark access; Debenhams (DB) which is located on the opposite end of the shopping centre with a single entrance on Newgate street with some street frontage and a single entrance in the Shopping centre on the main level facing the main corridor.

These selected anchor stores have each a different relationship to street frontage and to internal frontage. One is very present on the High street, one is fully dependent on the shopping centre, and the last one has equal street and internal frontage opportunities. The volumes of pedestrians passing through their entrances are recorded in Table 04.

<table>
<thead>
<tr>
<th>Entrances</th>
<th>Number of entrances</th>
<th>Average of people per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>IES</td>
<td>15</td>
<td>474.8</td>
</tr>
<tr>
<td>EG</td>
<td>5</td>
<td>14.4</td>
</tr>
<tr>
<td>Total shopping centre (street)</td>
<td>20</td>
<td>489.2</td>
</tr>
<tr>
<td>DB</td>
<td>2</td>
<td>66.9</td>
</tr>
<tr>
<td>FW</td>
<td>7</td>
<td>122.2</td>
</tr>
<tr>
<td>JL</td>
<td>9</td>
<td>95.8</td>
</tr>
<tr>
<td>Total anchor stores 18</td>
<td>18</td>
<td>284.9</td>
</tr>
<tr>
<td>street indoor</td>
<td>8</td>
<td>105.9</td>
</tr>
<tr>
<td>Total shopping centre (street)</td>
<td>8</td>
<td>105.9</td>
</tr>
<tr>
<td>indoor</td>
<td>10</td>
<td>179</td>
</tr>
</tbody>
</table>

Table 4 - Volume of pedestrians per entrance per minute (footfall). Comparison between the shopping mall entrances and accesses through anchor stores.
Figure 7 - Strategies to locate internal entrances: high visibility entrance (a) – alignment of entrances to form an axis (b) and multiplication of entrances (c). Lower right: diagram of entrances location and active frontage for the anchor stores.
The volume of people that uses in average the anchor stores to access and leave the premises of the shopping centre is around 100 people per minute (105.9 pp/min). One person out of 6 entering the shopping centre uses an anchor store entrance. From the three anchor stores, FW receives the more footfall at its entrances: 1.3 times more than JL and 1.8 times more than DB. Interestingly, JL which doesn’t have an external entrance has a larger volume of shoppers passing through its doors than DB. The diagonal entrance of the shopping centre connects to the internal entrance of FW and one of the main entrance of JL, both facing each other on opposite corners. From that same location, FW entrances receives 1.2 times more passage and both are slightly more used to exit the anchor store and enter the shopping centre.

One can observe that similar strategies used at the city scale to connect the shopping centre to its surroundings are applied to the location of entrances of shop internally (figure 07). FW capitalises on a single entrance located on a highly integrated space, JL multiplies the entrances to drain as much footfall as possible along the two corridors & DB and JL align their entrances creating a stronger axis.

<table>
<thead>
<tr>
<th>Entrance ID</th>
<th>count</th>
<th>location</th>
<th>pp/min IN</th>
<th>pp/min OUT</th>
<th>pp/min TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>2</td>
<td>Indoor</td>
<td>22.4</td>
<td>26.8</td>
<td>49.2</td>
</tr>
<tr>
<td>21</td>
<td>2</td>
<td>High street</td>
<td>12.6</td>
<td>17.2</td>
<td>29.8</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>Blackett st</td>
<td>11.8</td>
<td>7.5</td>
<td>19.3</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
<td>High street</td>
<td>6</td>
<td>3.7</td>
<td>9.7</td>
</tr>
<tr>
<td>22</td>
<td>2</td>
<td>High street</td>
<td>2.2</td>
<td>3.1</td>
<td>5.3</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
<td>Blackett st</td>
<td>3.2</td>
<td>1.9</td>
<td>5.1</td>
</tr>
<tr>
<td>26</td>
<td>2</td>
<td>Metro</td>
<td>1.2</td>
<td>2.6</td>
<td>3.8</td>
</tr>
<tr>
<td>total</td>
<td>2</td>
<td></td>
<td>59.4</td>
<td>62.8</td>
<td>122.2</td>
</tr>
</tbody>
</table>

Table 5 - volume of people per minutes entering and exiting the department/anchor store Fenwick. Summary of 2 observations on a Saturday midday (weekend peak time) and at 5.00pm on a Thursday (weekday peak time)

Looking at the footfall per entrance in a single shop (Table 05), the most used entrance is the one located inside the shopping centre (49.2 pp/min), which represents a little less than half the volume of all passages (122.2 pp/min). The aggregation of the 3 High street entrances provides a similar volume (44.8 pp/min). The 2 entrances on Blackett street combined accounts for half of the internal volume (24.4 pp/min). It seems that the department store relies equally on the high street and the shopping centre. From the 3 anchor stores, its connection to the high street seems to benefit the volume of shoppers passing through its doors.

7. FOOTFALL VERSUS NATURAL MOVEMENT

In the ‘fight’ for frontage, at the city scale, the High street wins over the shopping centre. When embedded into the surrounding fabric, the shopping centre has a lower integration value than when thought at its own system. The integration value of the High street and the street network overall benefit from the addition of the shopping centre circulation, with an increase of integration. At the accessibility level, the shopping mall is clearly building upon natural movement provided by the High street, and behaves like a traditional shop front. But it also

3 There is an overlap for entrance which is the carpark that directly connects to the anchor store, and is counted in both totals.
develops alternative configurations to maximise accessibility from different fronts: alignment of accesses and multiplication of entrances. At the shop scale, the internal entrances tend to have more volume of shoppers passing through their doors, shopping mall slightly wins.

One can observe that the local intensification of the grid that naturally occurs as a consequence of movement economies is replicated to some extent at the scale of the building. There is an intensification of access (1) that creates more interconnections, and inter-accessibility. The second type of configuration observed is the alignment of accesses (2) building on co-visibility at the city scale. At the level of the corridor, this co-visibility is dictated by the design (dumb-bell layout) which minimises the distance between two anchor stores. Following this principle, the high street can be seen as acting as anchor store (3) to the shopping centre which ‘entrance’ is directly linked to other anchor stores entrances (Figure 08).

Because of their proximity, the high street and the shopping mall tend to negotiate movement in a fairly complex way. Depending on the scale of observation, the shopping centre or the high street benefits differently from each other. Globally the high street gains by the addition of the shopping mall. The shopping centre either acts as a traditional shop that built upon the potential of the high street (generator), either considers the high street as another anchor store (attractor).

The distinction of generator versus attractor is legible in the way the two models of retail build on either natural movement or footfall. Both measure the presence of individuals but a distinction exists in the way they capture that presence. The success of a retail centre is measured by its footfall. Footfall embeds in its definition the notion of entrance and exit; it is linked to access points. Then the challenge of the shopping centre is to contain that footfall within its precincts. The first aim is to “attract” with in this instance a high density of retails within a single location and an ease of vehicular access; the second aim is to contain which is achieved by providing dining, entertainment, and shopping opportunities. But physically, the containment is achieved by creating an internal circulation loop and by placing the accesses to the exterior at the periphery, away and not visible from the main loop. The retails on the high street on the other hand are dependent on through-movement that is intensified by the presence of adjacent streets. The status of High street is often dependent on the presence of shops but the presence of these shops is primarily the result of its location within the overall city fabric.
Figure 8 - The High street as anchor store. Combination of the three modes of retail in a single model.
The problem is that when the attractor fails to attract, the shopping centre has no alternative to provide footfall. It is designed for a single purpose and when this purpose can’t be fulfilled anymore, it creates a space difficult to repurpose. In case of the High street, through movement will continue to exist without the presence of the attractors. The model of the shopping centre on the high street demonstrates how natural movement occurring on the high street contributes to the footfall of the shopping centre. In this case, the high street acts as anchor store of the shopping centre. It has shown that with providing the highest footfall, natural movement remains stronger than any attractor.

This study has aimed to clarify the role of natural movement within shopping malls when locate in traditional urban fabric. Secondly it has tried to understand accessibility and its impact on types of entrance and frontage. Future work is intended to provide a more comprehensive model for retail location, based on frontage and access with the implications of single or multiple frontages for retail unit value also being considered. A more in-depth and more exhaustive set of observation should then provide more clarification on how movement is generated. The observations were limited to thresholds and accesses and doesn’t fully take into account the linear frontage along the street and corridor. Observations should be made at the level of the street or corridor segment for a better understanding of the two structures.
REFERENCES


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THE EFFECT OF BRIDGES ON THE SPATIAL CONFIGURATION OF CITIES:
The Golden Horn, Istanbul case

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ABSTRACT
Throughout history, transportation projects have attempted to offer full accessibility for their users. In terms of the overall street pattern, bridges are considered to be components which shape the urban form and affect the spatial configuration of cities.

Transportation projects especially subways, bridges and new transportation modes such as tube tunnel, gained importance in Istanbul in the last decades. One of the projects; the Golden Horn Metro Bridge, which connects two parts of the European side of Istanbul (Sarıyer district in the north to Yenikapi, a major transport hub in the south) and has a station on the bridge, has caused major criticisms not just because of having these unique and significant characteristics but also because of the effects of the bridge on the silhouette of Historical Peninsula.

The main aim of this paper is to analyze the impact of bridges on their surrounding environments and to explore the different influences of metro and vehicular bridges. Within this scope, three bridges located over the Golden Horn (the Atatürk, Galata and Golden Horn Metro bridges) which created connections between historical site of Istanbul and the newly developed CBD are chosen as case study. Area within 1km (0.6 mile) zones around the three bridges were analysed, and GIS-based urban pattern (street pattern, block size and building utilization) and Space Syntax (angular segment based integration and choice implemented in Depthmap) analyses were conducted for demonstrating the changes in the spatial organization of the area before and after the construction of the bridges and for explaining the different effects of metro and vehicular bridges.

The findings of the study indicate that after the construction of the bridges spatial values of the surrounding urban form have increased and the area has become more intelligible. Additionally, the study area has transformed into more divided streets and urban blocks and the number of buildings increased through time. On the other hand, it is observed that the metro-rail bridge system has less impact on the pattern and spatial configuration of the settlements when it is compared with the impact of the vehicular bridges. This study contributes to urban planning and design not only by making an analysis of the impact of different kinds of bridges on the spatial character of cities, but also by analyzing the effects of bridges in a historical city and by drawing comparisons between the pre- and post-construction processes.
KEYWORDS
Urban morphology, spatial configuration, space syntax, the Golden Horn Metro Bridge, İstanbul

1. INTRODUCTION
The Golden Horn region of Istanbul constitutes an important historical part of the city. This area has changed dramatically during its long history and the bridges which have been constructed along the Golden Horn are significant examples of these changes. Due to the effect of these bridges, the form of the settlements on the Golden Horn has changed, and by examining this change, this study analyzes the major effects of bridges on the form and spatial structure of cities.

This study can be considered important because it analyzes not only vehicular-pedestrian bridges, but also a newly-constructed metro-pedestrian bridge over the Golden Horn of Istanbul. To analyze the effects of bridges on spatial configuration, pattern analyses prepared in GIS (Geographic Information Systems) for different periods were examined. Space Syntax, the methodology of which measures the connectivity and accessibility values of a street network, was utilized to support the morphological results.

Space Syntax is a methodology that was developed by a team led by Bill Hillier (Hillier, 1996). This methodology is important as it gives consistent results based on the mathematical data created according to the open spaces within cities. It provides unique evidence-based learning by creating a systematic framework that allows comparisons between environments to be made (Peponis, 1990). Therefore, in this study a comparison between close surroundings of bridges are made by the help of syntactic measures and pattern analysis.

The main goals of the study are:

- to explore and analyze the pattern of settlements of the Golden Horn and determine its level of transformation
- to analyze the spatial structure of the area by using Space Syntax and pattern analysis
- to discover the relationship between the urban pattern and changes in its syntactic measurements
- to discover the different effects of vehicular-pedestrian bridges and metro-pedestrian bridges on the urban form

2. METHODS
Within the context of this study, three bridges which span the Golden Horn; the Atatürk, Galata and Golden Horn Metro bridges (Figure 1) were selected to facilitate an analysis of the impact of bridges on settlements. These three bridges were selected since they make a connection between the neighborhoods of the Historical Peninsula, which is well-known for its historical background, and the newly developed CBD.

As a part of this study, not only the pre-, post- construction process of bridges but also two time periods, which urban pattern changed dramatically, were also analyzed. During the first – 1922 – the Islamic city image changed to that of a more cosmopolitan city; the organic pattern started to shift toward a grid pattern and the Republic was about to be proclaimed. In addition to this, a tram line was added to the Galata bridge. During the second – 1996 – several planning decisions were implemented in the study area, thus the patterns of the settlements were changed.
Empirical evidence was used to determine 1km as a distance that people can, and do, walk (Lee and Moudon, 2006). To determine the specific study area, 1km zones around the bridges were created and the road segments at the edge of these zones were selected as the boundaries of the study area. Natural borders and boulevards were also considered to specify certain borders. Thus, this area can be described as:

- a region with a focus on bridges
- a pedestrian-scaled urban space
- a border that allows the effect of bridges on urban pattern to be observed more easily, and
- Divanyolu boulevard (the Mese, or main street of Constantinople) as the southern border of the study area (Figure 2).

Following this, morphological analyses such as:

- street patterns
- urban blocks
- building level land use were conducted in ArcMap 10.3.1.

To support this data, Space Syntax methodology was integrated into the study to allow angular analyses such as connectivity, integration $r_{12}$, choice $r_3$ and choice within 500 meters values by using UCL Depthmap 10 software (these measures are selected since these values show more significant results). Finally, these analyses were added to a table to allow comparisons to be made.
THE EFFECT OF BRIDGES ON THE SPATIAL CONFIGURATION OF CITIES: The Golden Horn, Istanbul case

3. ANALYSIS

3.1. HISTORICAL PROCESS OF THE BRIDGES

Historical background of the bridges over the Golden Horn dates to 1830s (Figure 3). Both the Galata and Atatürk bridges were originally constructed during the Ottoman period, while the Golden Horn Metro Bridge was constructed during the Republican period. These bridges are of great importance because they are located on the Historical Peninsula, which is listed as a World Heritage Site.

In 1836, the first historically-verifiable bridge was built across the Golden Horn. The bridge connected Azapkapı and Unkapanı, and was about 600m in length and 10m in width. The main reason for the construction of the bridge was the location of the imperial shipyards in Azapkapı. In addition to this, Pera(Beyoğlu) and Beşiktaş were not developed enough in the 1830s to support a connection between Karaköy and Eminönü, and Karaköy was not yet a busy trade centre, though it became so after 1838 (Celik, 1993).
After this period, with the effect of increased transportation system between Karaköy and Eminönü, the Sultan began to reside in a palace at Beşiktaş, known today as Dolmabahçe Palace. The population of Beşiktaş and Beyoğlu increased, and horse carts imported from Europe became more widespread. Therefore, the “Cisr-ı Cedid” bridge, now known as the Galata Bridge, was built in 1845 (Cekmis Gorgulu and Hacihasanoglu, 2012). The original bridge served Istanbul for about 12 years, but discussions about replacing its wooden structure with one of iron began in 1869. The new bridge design was planned by an English company; it was to have been about 460m long and 18m wide, with 1.5m wide pedestrian sidewalks on both sides. The government agreed to the construction of the project, but the bridge plans underwent some changes (Celik, 1993).

A new Galata bridge was built in 1912 and the old bridge was moved to a place between Unkapanı and Azapkapı. The new bridge had more advanced technology that allowed a tram line. Following this, replacement and reconstruction of the bridges continued during different periods. In 1936 Unkapanı bridge broke into pieces as a result of a powerful storm. Therefore, in 1940 Atatürk Bridge was constructed between Unkapanı and Azapkapı. In the 1970s an agreement was made for a new bridge with Japanese-German company. The bridge which is still in use having had much extension work carried out at several times has become a very important and busy highway. In 1987, construction work for the Galata Bridge of today started. This bridge has a drawbridge-style opening at its centre which allows ships to sail through an 80m gap (Cekmis Gorgulu and Hacihasanoglu, 2012).

3.2. CONSTRUCTION PROCESS OF THE GOLDEN HORN METRO BRIDGE

The construction process of the Golden Horn Metro Bridge first started with an announcement by the mayor of metropolitan Istanbul, Kadir Topbaş, in 2004. He announced that there would be a new metro bridge, and that it would become a new landmark for Istanbul (Vardar, 2014). With the construction of the metro bridge, the underground line from Hacıosman, (passing through 4th Levent, Taksim and Şişhane), would reach the Yenikapı terminal and transfer station after crossing the Golden Horn (Cekmis Gorgulu and Hacihasanoglu, 2012). The project was approved in 2009 by the Conservation Board. Although the Historical Peninsula, where an abutment of the bridge is located, had been on the World Heritage Site list since 1985, the bridge project was not reported to UNESCO (Vardar, 2014). In 2009, when the construction of the project began, UNESCO stated that this project would damage the silhouette of Suleymaniye and the Historical Peninsula and warned that the area could be added to the World Heritage in Danger category (Bilgehan, 2015). After this warning, the project was revised and the height was decreased from 82 meters to 65 meters and construction work was halted until 2011 (Vardar, 2014). In 2012, the revised design of the project was approved and construction started again. The bridge eventually entered service in February 2014 (Figure 4).
3.3 PATTERN ANALYSIS

In the 1830’s, the Historical Peninsula was the center of the settlement and the Galata region was limited by its old borders. Outside these borders, however, there were newly developing settlements (Figure 5).

During this period, as shown in the figure below, the continuous street segments along the Golden Horn shoreline were notable. The street pattern of the time was usually organic, except at the north side of the Golden Horn and the south-western side of the study area.

Also during this period, the number of street segments totalled 437, while the average length of the streets was 152 meters. Additionally, the number of dead-end streets totalled 35 and the number of urban blocks totalled 148.

After the construction of the two bridges (in 1850), there were some changes to the morphological characteristic of the area. The number of street segments increased from 437 to 479, and the number of urban blocks increased from 148 to 185. Furthermore, some parts of organic street pattern located between the two bridges on the Galata side were rebuilt according to a grid pattern.

In addition to these impacts, the Galata Bridge became a part of the urban identity and the region around the bridge became known as Galata. The bridge became a symbol of the connection between the European and Turkish cultures as well as a physical connection between the two shores (Kuban, 1996).

During the 20th century, there were many different processes underway in the study area. Therefore, it was constructive to conduct an analysis across two different time periods. First, in 1922, when the Republic was about to be proclaimed and a tram lane was added to the Galata Bridge, the number of street segments increased from 479 to 2454, and the number of urban blocks increased from 185 to 828. The average area of the urban blocks decreased from 27177 to 5732 square meters and the number of buildings increased from 721 to 811. The most important buildings were the Sirkeci railway terminal (on the Historical Peninsula), two hospitals (Beyoğlu and Sankt Georgs) and the town hall (located in Galata). Additionally, after the establishment of the Republic of Turkey, Topkapı Palace was transformed into a museum at the date April 1924 and it was also the first museum of the Republic of Turkey. Ministry of war was transformed into a university building in 1923.

Second, in 1996, after the planning processes around the Golden Horn, the number of street segments increased to 2568 and the average area of the urban blocks decreased to 5449 square meters. The number of dead-end streets decreased from 127 to 107.

In 2006, before the construction of the third bridge (the Golden Horn Metro Bridge), the number of urban blocks increased from 876 to 1088 while the average area of the urban blocks decreased from 5450 to 4526 square meters. In addition, the number of street segments increased from 2568 to 3654 and the average length of the streets decreased from 58 to 48 meters. In addition to this, the study area now contains Istanbul Ticaret University and Kadir Has University.

In 2016, after the construction of the bridge, the number of street segments decreased from 3654 to 3648 due to the changing function of the shoreline. Additionally, the number of urban blocks decreased from 1088 to 1064, and the number of dead-end streets increased from 232 to 237.
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Figure 5 - Changes in the urban form of the Golden Horn (only pre- and post- construction processes of bridges are shown in the figure)
3.4 SYNTACTIC ANALYSIS

In 1831, the highest value for choice (R3) was on the shoreline of the Golden Horn (Figure 6). On the other hand, the choice within 500 meters value was significant in both the Galata and the Historical Peninsula regions while the integration (R12) value was high in the Historical Peninsula. The integration (R12) and choice (R3) analyses emphasized three roads, the Ragıp Gümüşpala, Kadir Has and Atatürk boulevards. Galata Tower and its surroundings were defined as having high choice values. Unlike the integration analysis, the choice within 500 meters values do not show a hierarchical order. In 1831, the intelligibility value of the area was 0.196.

In 1850, connectivity measures moved towards the new bridge, and the highest integration value for R12 and choice value of radius 3 were recorded for Ragıp Gümüşpala Boulevard and the Galata Bridge. Additionally, high integration (R12) values continued through the south side of the Galata Bridge area. Moreover, the choice within 500 meters value was higher around the Galata Bridge, the Spice Bazaar and Galata Tower. It can be said with the effect of new bridge, the higher choice within 500 meters values moved from the Unkapanı Bridge to the Galata Bridge.

The street network configuration in 1922 showed significant changes and an increase of the values for choice (R3) (from 3.14 to 3.28), connectivity (from 3.25 to 3.31) and integration (R12) (from 7.29 to 7.61). Accessibility of the area increased dramatically in this period due to the urban form changes, and both the Galata and Unkapanı bridges recorded the highest integration (R12) values. The Atatürk, Tersane, Ragıp Gümüşpala and Kadir Has boulevards were also defined by having the highest integration values. The choice (R3) value and choice within 500 meters value did not show any hierarchical order during this period. The intelligibility value was 0.223.

In 1996, street connectivity measures; connectivity increased from 3.31 to 3.41, the choice (R3) value increased from 3.28 to 3.30, and the integration within 500 meters value increased from 7.60 to 7.65.

The integration analysis of the area verified the significance of the Atatürk Bridge, as well as the Atatürk and Şehzadebaşı boulevards. Choice (R3) values were high for the Atatürk, Ragıp Gümüşpala and Banks boulevards.

In 2006, the most integrated space was still the Atatürk Bridge and its connection to the Kasımpaşa neighborhood. The choice (R3) value increased from 3.30 to 7.15 and the choice within 500 meters value increased from 3.34 to 6.97. Additionally the integration (R12) value increased from 7.45 to 7.57. In terms of choice (R3) and choice within 500 meters, Evliya Çelebi and Refik Paşa Boulevard have higher values. The intelligibility value dramatically increased to 0.347 in this time period.

The choice(R3) value and choice within 500 meters value were same before and after the construction. The integration (R12) value increased from 7.57 to 7.59 in 2016. This analysis emphasized the importance of the Atatürk Bridge, and the Refik Saydam and Evliya Çelebi boulevards. Furthermore, the Tersane, Ragıp Gümüşpala boulevards and Atatürk Bridge are distinguished by their high integration values, as are the Galata and Golden Horn Metro bridges. The choice (R3) value and choice within 500 meters value verified the significance of the Refik Saydam, Evliya Çelebi, Tersane boulevards and the Atatürk Bridge. The intelligibility value increased to 0.372 in 2016.
THE EFFECT OF BRIDGES ON THE SPATIAL CONFIGURATION OF CITIES: 
The Golden Horn, Istanbul case

Figure 6 - Changes in the spatial values of the Golden Horn (only pre- and post- construction processes of bridges are shown in the figure)
4. RESULTS

Results of the study demonstrated that with construction of new bridges:

- number of urban blocks increased and blocks are divided by new streets or boulevards (Table 1)
- as the number of urban blocks increased, the average area of the urban blocks decreased
- syntactic measures; choice and integration values increased after the construction of the vehicular bridges (Table 2)
- especially after the construction of the second bridge, the number of buildings and new functions have increased (Table 3).
- intelligibility of the study area increased after the construction of the bridges.

<table>
<thead>
<tr>
<th>Date</th>
<th>2016</th>
<th>2006</th>
<th>1996</th>
<th>1922</th>
<th>1850</th>
<th>1831</th>
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<td>3654</td>
<td>2568</td>
<td>2454</td>
<td>479</td>
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<tr>
<td></td>
<td>Average Length of Streets (m)</td>
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<td>48</td>
<td>59</td>
<td>56</td>
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<td></td>
<td>Number of Deadends</td>
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<td>232</td>
<td>107</td>
<td>127</td>
<td>12</td>
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<tr>
<td>Urban Blocks</td>
<td>Number of Blocks</td>
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<td>1088</td>
<td>876</td>
<td>828</td>
<td>185</td>
</tr>
<tr>
<td></td>
<td>Average Area of Blocks (m²)</td>
<td>4578</td>
<td>4526</td>
<td>5450</td>
<td>5733</td>
<td>27377</td>
</tr>
<tr>
<td>Buildings</td>
<td>Number of Buildings</td>
<td>858</td>
<td>858</td>
<td>812</td>
<td>811</td>
<td>721</td>
</tr>
</tbody>
</table>

Table 1 - Urban form characteristic of the area around the bridges

<table>
<thead>
<tr>
<th>Date</th>
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<th>2006</th>
<th>1996</th>
<th>1922</th>
<th>1850</th>
<th>1831</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syntactic Values</td>
<td>Connectivity</td>
<td>2.40</td>
<td>2.40</td>
<td>3.41</td>
<td>3.31</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td>Choice R3</td>
<td>7.15</td>
<td>7.15</td>
<td>3.3</td>
<td>3.28</td>
<td>3.14</td>
</tr>
<tr>
<td></td>
<td>Choice 500 metric</td>
<td>6.97</td>
<td>6.97</td>
<td>3.34</td>
<td>3.46</td>
<td>2.45</td>
</tr>
<tr>
<td></td>
<td>Integration R12</td>
<td>7.59</td>
<td>7.57</td>
<td>7.45</td>
<td>7.61</td>
<td>7.89</td>
</tr>
</tbody>
</table>

Table 2 - Average syntactic values of the area around the bridges
THE EFFECT OF BRIDGES ON THE SPATIAL CONFIGURATION OF CITIES: The Golden Horn, Istanbul case

Table 3 - Building utilization of the area (m²)

<table>
<thead>
<tr>
<th>Date</th>
<th>1831</th>
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<th>1922</th>
<th>1996</th>
<th>2006</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>R²</td>
<td>0.196</td>
<td>0.144</td>
<td>0.223</td>
<td>0.137</td>
<td>0.347</td>
<td>0.372</td>
</tr>
<tr>
<td>Significance</td>
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<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>N</td>
<td>917</td>
<td>1100</td>
<td>4656</td>
<td>4665</td>
<td>22558</td>
<td>22500</td>
</tr>
</tbody>
</table>

Table 4 - Correlation of bivariate connectivity and integration(n) data for different time periods

**. Correlation is significant at the 0.01 level (2-tailed).

Finally, intelligibility is a value which is derived from the correlation between connectivity and integration. A high correlation between two factors means that the spatial structure is intelligible, and low correlation means that the spatial structure is not intelligible. Kubat (1997), discovered that the intelligibility value of the Anatolian towns she analyzed was 0.350, while that of the Islington area of London has been reported at 0.61-0.26 (Hillier, 1989), and that of Athens has been reported at 0.790 (Peponis et al., 1989). Also Pinho and his colleagues determined that global intelligibility value of Oporto (Portugal) was about 0.076 in 2005 (Pinho and Oliveira, 2009). Therefore, it can be said that the intelligibility value of the study area (Table 3) remained weak until 2006, and that this value then became similar to the finding of Kubat’s Anatolian towns. As an overall assessment, the intelligibility value of the area has increased, and it has become a place where people can learn about its large patterns from their experience of its smaller parts.

5. CONCLUSIONS

As a result of these analyses, it is possible to state that the study area has transformed into more divided streets and urban blocks, and the number of buildings increased after the construction of the bridges. Therefore, as planned, Galata and Karaköy regions have become more accessible and more preferred areas; thus, new functions and buildings have been constructed. Although it is not possible to claim that the bridges are the only factors behind these changes, it can be stated that the bridges have created more accessible spaces. Although the bridges generate more accessible spaces on both sides of the Golden Horn, they created more complicated and crowded districts.
This study is an attempt to contribute to the literature by explaining the influences of bridges on urban morphological characteristics and street network configurations. Furthermore, it is clear that the metro bridge-rail system of the Golden Horn Metro Bridge has had less impact on the pattern of the settlements when it is compared with the impact of the vehicular bridges. The primary reason for this lower values is that there is no distinct, continuous pedestrian route in the north-west direction. Golden Horn metro bridge was built as a separated metro bridge which passes through the existent urban blocks and has only a pedestrian connection with the coastal area. Since it creates no significant change in the existing urban pattern, it shows low spatial values. There is no concern on the linkage of the pedestrian activities. However, just as with the Galata and Atatürk bridges, it is expected that with some new planning decisions (new routes connected to the main sidewalks and new functions around the Golden Horn Metro Bridge), the settlements around the bridge will become more accessible and integrated spaces. In conclusion, it is possible to state that bridges create more intelligible and accessible spaces, and because of the increases in choice values that they produce, they affect preference rates within nearby settlements. Furthermore, new buildings with different functions can be integrated into neighborhoods which are close to bridges. Finally, the increased accessibility provided by bridges allows city development to be better organized.

6. NEXT STEPS

There should be future studies to analyze the new tube tunnel project planned for the Golden Horn. This tube tunnel project, which was announced by the mayor of the Istanbul Metropolitan Municipality, is intended to connect the Unkapanı region and the Kasımpaşa neighborhood. It is currently expected that this project will go into service in 2018, and will include the removal of the Unkapanı Bridge, thereby triggering a new series of transformations (Istanbul Metropolitan Municipality, 2016). It is expected that this study will be a beneficial source for future studies into the historical process and spatial changes that affect the neighborhoods which develop around bridges.
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SYNTACTIC STITCHING: Towards a Better Integration of Cairo’s Urban Fabric

ABSTRACT

This paper focuses on studying Cairo’s urban fabric, which is composed of a mixture of planned districts built by the government and private sector, and informal districts, self-generated to fulfil the needs of a rapidly expanding population. The case studies selected are continuous parts of the city that show variation in the urban fabric and a distinction between planned and informal districts. This paper argues that even though there is a high percentage of unplanned districts in close proximity to planned districts, the city as a whole functions and is connected. This indicates that there exists an underlying, naturally generated global structure, a super-grid, which can be used to better integrate between the different districts, both planned and informal (Peponis et al., 2015). The study will show variations between the selected districts in terms of emergence, morphology and syntactical structure. The study will analyse syntactically the selected districts as they currently exist both locally within the district and globally in the entire case study. A similar analysis was conducted on informal settlements in Santiago, Chile. One of the principle findings was that the more spatially integrated the existing settlement is on its edge boundary with the surrounding urban layout, in terms of vehicular movement and local accessibility, the higher the level of self-generated economic activity and community development (Hillier, Greene, & Desyllas, 2000). This paper aims to build upon that, by exploring ways in which the existing informal settlements can be better integrated with the surrounding urban form to benefit the entire community by harnessing the super-grid. The analysis indicates that the highway super-grid is based on the pre-existing canal system in Cairo, but it is incomplete and creates a boundary around informal settlements rather than becoming a connector. The analysis also indicates that the main roads in informal settlements have developed using the same canal system super-grid and that this can be used to reconnect them to the city. After the initial syntactical and morphological analysis of the existing fabric, different approaches to create ‘syntactic stitching’ between the districts are suggested following the previous analysis and underlying global structure. The focus is on adjusting the existing fabric, such as aligning existing streets, creating new thoroughfares to increase edge movement and consolidation into the main urban form.

KEYWORDS

Informal Settlements, Boundaries, Syntactic Stitching, Spatial Integration, Super-grid
1. INTRODUCTION

This paper presents a case study on the western bank of the Nile in Cairo composed of a mixture of planned and informal settlements in close proximity, a pattern that’s repeated throughout Cairo. In this case study, the main transport highways form boundaries and overpass the informal settlements, creating a disconnection between the local neighbourhoods and the global city. These settlements have a coherent local structure but lack citywide connectivity. This increases segregation in the urban fabric and leads to lack of access to resources and services. It also increases densification within informal settlements, as they cannot grow outwards due to the highway hard edges, which leads to increased social segregation and lack of consolidation into the main urban form.

![Satellite Imagery showing the case study highlighted in pink within the wider context of Cairo](image)

Figure 1 - Satellite Imagery showing the case study highlighted in pink within the wider context of Cairo

1.1 INFORMALITY IN CAIRO: AN OVERVIEW

The estimate from the Ministry of Housing is a quarter of Greater Cairo is informal settlements, but independent researchers have placed that figure at more than half, with some estimates reaching two-thirds, depending on their definition of “informal”. The richest of the citizens live in desert satellite cities and gated compounds while the majority live in deteriorated planned areas or illegal, informal settlements (Sims, 2010).

1.2 STATE POLICY AND AL-MAJHUD AL-DHATI

In order to study informality, the state policies and laws that led to its growth must be examined. With the 1952, revolution came laws to change land ownership, known as the Land Reform Laws under Gamal Abdel Nasser’s Arab Socialism. Before the revolution, 3% of the population...
owned 80% of cultivated agricultural land, with farmers renting their land from the aristocracy at high prices and taking on debts. The laws aimed to increase land ownership by allowing farmers to pay off the land over 30 years and set a limit of 200 feddans (100 acres) to the land one family could own. Land that was confiscated from families that owned above the limit was redistributed to the landless farmers (fellahaen) which comprised approximately 20% of the population (Osman, 2010).

After a number of revisions, these laws were abolished in the 1980’s with the rise of neoliberalism, but the farmers that owned their land retained ownership. In the 1980’s there was a period of rapid urbanisation, with the state encouraging construction and self-reliance under the neoliberal ‘Infitah’ or Open Door Policy, which aimed to increase private investment but led to reduced state social spending on housing, education and healthcare. It was then informal settlements started to make an appearance (Singerman & Amar, 2006). With citizens finding their needs not being met by the state they took matters into their own hands, building residences on their privately owned, agricultural land which eventually linked together to form coherent neighbourhoods. The residents linked these settlements to the utility and power networks, which was later formalised by the government. This gave rise to the concept of ‘Al-Majhud al-Dhati’, translated into ‘Self Reliance’, similar to the English phrase ‘pulling oneself up by the bootstraps’ (Ben Nefissa, 2011).

1.3 SPACE SYNTAX ANALYSIS IN CAIRO – SEGREGATION AS A WAY OF LIFE

A study conducted in 2014 analysing Cairo’s urban structure and urbanisation process as a whole using space syntax methodology found that spatial segregation contributes to social segregation. The study also showed that the way in which new highways are constructed contribute to spatial segregation, separating neighbourhoods (A. A. Mohamed, et al, 2014) The main highway in Cairo, the Ring Road, is 8 lanes wide and 72km long. Part of the Ring Road passes through urbanised areas and agricultural land, creating an edge where neighbourhoods cannot expand and pedestrians cannot cross to reach other neighbourhoods, intensifying segregation. The type of settlement that emerge on agricultural land are usually informal, so this type of segregation disproportionately affects them.

As described by Hillier (2010) there exists a deformed wheel structure on a metropolitan level but this global network is poorly connected to local neighbourhoods (A. A. Mohamed et al., 2014). The deformed wheel is a semi-grid that forms in most cities, consisting of a central hub (core) of movement lines and a spatial rim, connected together by ‘spokes’ radiating from the core to the rim. This tends to indicate a more cohesive city and shows the public space structure in the city (Hillier & Stoner, 2010). On a global level in Cairo, this exists, but on the local level, the edge movement is not given a chance to form since the highways segregate neighbourhoods. Another study undertaken in the city of Assiut in Upper Egypt again looked at the city as a whole, with findings making the case for interventions that would alleviate the city’s morphological issues, namely conflicting spatial patterns that led to segregation and high levels of congestion. This would increase integration, creating a more efficient grid on both the global and local scale (A. M. R. Mohamed & Brown, 2009). Both these studies support the need for integration and started investigation into a ‘super-grid’ that can have local grids integrated into it.

1.4 SPACE SYNTAX IN INFORMAL SETTLEMENTS

One of the most significant studies using space syntax analyses in informal settlements was conducted in Santiago, Chile. One of the principal findings was that the more spatially integrated the existing settlement is on its edge boundary with the surrounding urban fabric, in terms of both vehicular movement and pedestrian accessibility, the higher the level of self-generated economic activity and community development. The spatial layout of the settlement and its relation to the wider urban context is one of the key factors in determining how well the settlement becomes consolidated within the larger urban fabric (Hillier et al., 2000). This gives an indication on why the informal settlements on the outskirts of Cairo are often considered
less economically active, since they are not well consolidated in the urban form because the highways form a hard edge where the edge movement of that settlement should be.

A study conducted in 2007 in unplanned areas at the core of Jeddah, Saudi Arabia, indicates that limited physical interventions can enhance unplanned areas and contribute to the overall spatial integration of Jeddah. It presents similar a similar case to the urban fabric in Cairo; neighbourhoods that have a distinct local structure that doesn't fit into the global structure (Karimi et al., 2007). The minor physical interventions proposed could be applied to Cairo, however the settlements in this paper are at the edge of the main city rather than at the core.

1.5 THE SUPER-GRID

The super-grid is a way of differentiating between scales in the street network; the super-grid itself consists of the primary road network, which then have local roads inserted into it. Another way of looking at it is to consider the primary road network as creating 'super blocks' and the local roads creating urban blocks. Within one super-block exists a neighbourhood, with the local streets either connecting to the super-grid of primary streets or forming a secondary network of minor streets. The super grid shows evidence of integration at the global scale; it starts with/includes to some extents the extension and peripheral streets of the deformed wheel. The super-grid and the local streets should be designed to interact with one another to promote connectivity, and there are four syntactical principles that can arise from the interaction of the super-grid with the local grid. Shortcut, which means that movement does not need to pass through the super-grid; Bypass, where the super-grid bypasses the local grid's density, possibly resulting in faster movement; hierarchal, where the super-grid has fewest directional changes; and labyrinth, where the paths inside the local grid are shorter but the shortest route involves the super-grid. In general, the super-grid is more integrated than the system as a whole; however, the 2015 study deals with regular, linear grids (Peponis et al., 2015). In this paper it is proposed that there is a super-grid linking the neighbourhoods together that accounts for the apparent functioning of Cairo as a whole even with the major spatial and morphological differences between neighbourhoods. In this case study, the highway super-grid can be classified as bypasses, with the informal settlements containing shortcuts but with disconnection between the two.

2. METHODOLOGY

2.1 CASE STUDY SELECTION AND BOUNDARY DETERMINATION

The case studies selected are located in western Greater Cairo, where planned and informal settlements are in close proximity to each other. Boundaries were determined by using 'apparent villages' rather than official government boundaries, which are different from how people perceive the settlements. The types of boundaries encountered include highways, roads, and the Nile. Where an unclear boundary exists, as is the case with the Al-Mohandiseen and Al-Sahafiyeen district, the 'street face' of neighbouring districts was included in the analysis since that is what the district interacts with as an autonomous unit.

2.2 SYNTACTIC ANALYSIS

The axial maps were generated in DepthmapX and analysis ran for both global and local integration. Open spaces that were not used as part of the natural pedestrian movement (e.g. open fields in the case of the informal settlements, and private sporting clubs in the case of the planned settlements, see fig.2) were disregarded in the analysis. The informal settlements were analysed by drawing axial lines between parcels, since the proximity of the buildings means that passing between them is difficult, especially for non-residents. The informal settlements also do not follow the building code for setbacks or maximum height, so most buildings are built to the edge of the plot and the resulting streets are very narrow, usually less than 3m. The planned settlements were analysed by building since there are setbacks and both residents and non-residents can pass between buildings (Howeidy et al., 2009).
3. HISTORICAL DEVELOPMENT OF THE CITY’S URBAN MORPHOLOGY

3.1 GEOGRAPHY

The sample encompasses various types of urban forms: organic, planned and informal. A distinction is to be made between organic and informal. Both are non-planned but differently structured due to the rate of growth and different type of aggregation; informal settlements tend to grow at a higher rate than organic settlements. From a morphological perspective, they are different in that historical organic settlements, the buildings aggregate to form enclosed public space, similar to mediaeval Islamic cities (Bianca, 2000).

1. Addition/Aggregation (Organic)
   In this case, individual cells (buildings) cluster together over a long period to form public space, creating small, dense groups of buildings with no apparent pattern. This type of growth is driven by the building, with the streets formed by the left over space after the buildings have clustered.

2. Infill (Informal)
   This type of morphology is created when there is a pre-existing grid, in this case the grid of the agricultural land, and the buildings fill in the plots created by the grid. This type of growth is driven by the plots, and the streets are the edges of the plots, in this case the dirt paths used to access the agricultural land. This usually results in a very long block and narrow streets. The plot size and shape is a major influence on the buildings’ size and shape and the resulting streets.

3. Setback on Parcel/Subdivision (Planned)
   This type is considered planned, the plots, buildings and streets are planned simultaneously, and streets form blocks that are split into parcels then have buildings built on the parcel with setback. The plot shape does not necessarily influence the building’s shape but there is usually a setback or height limit imposed by the planning authorities.

Each morphology creates distinctive syntactic configuration within the hard boundaries.

Figure 2 - Three Morphological Types
3.2 URBAN MORPHOLOGY OF DIFFERENT CASE STUDIES

<table>
<thead>
<tr>
<th></th>
<th>Al-Mohandiseen</th>
<th>Al-Sahafiyeen</th>
<th>Ard El Lewa</th>
<th>Bulaq El Dakrour</th>
<th>Mit Uqaba</th>
<th>Zamalek</th>
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<tbody>
<tr>
<td>Date</td>
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<td>1949</td>
<td>Approx. 1980’s</td>
<td>1560</td>
<td>Approx. 1900’s</td>
<td>1869</td>
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<td>3.08</td>
<td>3.75</td>
<td>0.47</td>
<td>2.46</td>
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<td>Data not available</td>
<td>49,000-250,000</td>
<td>75,000</td>
<td>Approx. 20,000</td>
</tr>
</tbody>
</table>

Table 1 - Showing the classification and statistical details of each settlement

Ard El Lewa

[Map of Ard El Lewa with years 2004, 2010, and 2016, showing the evolution of the area.]

SYNTACTIC STITCHING: Towards a Better Integration of Cairo’s Urban Fabric
Figure 3 - The urban morphology of the case studies

SYNTACTIC STITCHING:
Towards a Better Integration of Cairo's Urban Fabric

Proceedings of the 11th Space Syntax Symposium
3.2.1 ARD EL LEWA

Ard El Lewa became its own administrative unit in 1999, and since then the neighbourhood alliance has been conducting its affairs. The residents built their own access ramp to the 26th July corridor without government assistance to connect themselves to the wider urban network. The 26th July corridor flyover creates a boundary to the north of Ard el Lewa proper, and the upper part of the settlement is technically part of Imbaba. The syntactic axial analysis treats them as two distinct settlements because of the hard edge of the highway. As reflected by the actions of the residents, there exists a need to connect to the rest of Cairo and the surrounding urban fabric.

This is the only settlement to have experienced rapid growth in the past 12 years. The linear grid reflects land ownership – the linear pattern is in agricultural land and the plot size reflects the measurements used by Egyptian landowners (kirat, feddan). The dimensions of the average land parcel are 450m x 25 m, when split into plots of land is approximately equal to one kirat, or 175m2. This can be seen in figure 4, which shows the process of infill the settlement went through. Stage one shows the agricultural land as it originally was, split into plots with dirt paths and the canal system irrigating the land. Stage two shows the canals dried up and transformed into roads, with spare and random buildings. The final stage shows the urban fabric as it is now, fully densified with the local access between buildings not visible. In stage four, that shows the base grid, the initial dirt paths between the agricultural lands were perpendicular to the canal that irrigated that part of the land, which means that not all the paths are aligned. These T-junctions, rather than crossings, prevent the formation of long north-south axis in the informal settlements, which means that the dried up canals become the main movement thoroughfares.

3.2.2 BULAQ EL DAKROUR

Bulaq is the oldest settlement in this study, having been Cairo’s major port in 1560, and became an industrial district in the 19th century under Mohamed Ali’s rule. Over time, it has been the location of rapid urbanisation, with old housing and buildings being demolished to make way for high rise apartment blocks. Some areas retain the organic morphology while others have become informal (‘Bulaq | district, Cairo, Egypt’, n.d.).

3.2.3 MIT UQABA, AL-MOHANDISEEN AND AL-SAHAFIYEEN

Mit Uqaba is an historic village, which is situated in the middle of the Al- Mohandiseen neighbourhood. It is visible on the original Survey of Egypt maps from 1939 and the Al-Mohandiseen district was planned around it, starting in the 1950s as single storey villas and experiencing a building boom in the 1970s with high-rise apartment blocks being built and surrounding Mit Uqaba. In 1999, a large area of Mit Uqaba was demolished to build the 26th of July corridor, which resulted in splitting the village since there was no access to the corridor from the village and pedestrians could not cross it (Tadamun, 2013). Al-Sahafiyeen was built concurrently with Al-Mohandiseen, but is considered a different area since Al-Mohandiseen was originally planned to provide residence for Egypt’s engineers, and Al-Sahafiyeen was planned for journalists (ETH Studio Basel, 2008b).

3.2.3 ZAMALEK

Zamalek is situated on Gezira Island of the Nile and is one of the most affluent areas of Cairo. In 1863-79, it was a botanical garden under Khedive Ismail, and in 1890, a master plan drawn up that consisted of palaces for the rulers and nobility. In the 1940’s it began being known as Zamalek. It is divided into two sections, the upper affluent residential area and the lower are which contains the Gezira Sporting Club and Cairo Opera House (ETH Studio Basel, 2008a).
Figure 4 - Showing the progression of land subdivision in Ard El Lewa to create its distinctive urban morphology, as well as the misalignment of streets that creates T-junctions rather than intersections (red circle).
3.3 CAIRO’S HIGHWAYS AND CANALS

During the early 20th century, there existed a canal system stemming from the River Nile to irrigate the surrounding agricultural land. This was before the expansion of Cairo, when the majority of the population were farmers.

Figure 5 - Map of the case study area in 1930 showing the majority of Cairo on the eastern bank of the Nile. The western bank is agricultural land with scattered villages (Mit Uqaba (red circle) and Bulaq el Dakrour (blue circle) are the notable ones) and the canals irrigating the agricultural land. (source: Survey of Egypt Maps, Rare Books and Special Collections Library; the American University in Cairo)

Looking at the urban fabric of Cairo today, it is evident that the layout of the canals and the agricultural land has influenced the resulting urban morphology of Cairo, creating a super-grid pattern that is followed by both planned and informal settlements. In Cairo, the super-grid manifests as the highway system, which, in theory, connects the neighbourhoods of Cairo together. The main roads in the highway system are the Ring Road, which was designed to limit the growth of Cairo, the 26th of July Corridor, Gesr El Suez, the Autostrad (El Nasr Road) and Salah Salem, which were designed to link the neighbourhoods of Cairo to each other and to the Ring Road. Together they create a complex system of roads, bridges and flyovers that span the entirety of the city. However, due to the lack of pedestrian movement by these highways and the fact that they are very difficult to cross means that they end up creating a hard edge around neighbourhoods, as well as overpassing informal settlements which then have no connection at all to the super-grid.
4. SYNTACTICAL ANALYSIS OF INDIVIDUAL SETTLEMENTS

<table>
<thead>
<tr>
<th></th>
<th>Bulaq El Dakrour</th>
<th>Mit Uqaba</th>
<th>Al Mohandiseen</th>
<th>Al-Sahafyeen</th>
<th>Zamalek</th>
<th>Ard El Lewa</th>
</tr>
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<tbody>
<tr>
<td><strong>Global Integration (n)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum</td>
<td>2.453</td>
<td>1.616</td>
<td>4.050</td>
<td>5.159</td>
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<td>Average</td>
<td>1.458</td>
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<td>2.187</td>
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<td>Minimum</td>
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<td>1.477</td>
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<td>Standard Deviation</td>
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<td>0.428</td>
<td>0.552</td>
<td>0.398</td>
<td>0.241</td>
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<tr>
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<tr>
<td>Maximum</td>
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<td>5.343</td>
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<tr>
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<td>2.416</td>
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<td>0.618</td>
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<tbody>
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<td><strong>Global Integration (n)</strong></td>
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<td></td>
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<tr>
<td>Maximum</td>
<td>2.441</td>
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<tr>
<td>Average</td>
<td>1.449</td>
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<tr>
<td>Minimum</td>
<td>0.679</td>
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<tr>
<td>Standard Deviation</td>
<td>0.289</td>
<td>0.257</td>
<td>0.241</td>
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<tr>
<td><strong>Local Integration (n=3)</strong></td>
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</tr>
<tr>
<td>Maximum</td>
<td>5.344</td>
<td>4.937</td>
<td>4.445</td>
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<tr>
<td>Average</td>
<td>2.722</td>
<td>2.581</td>
<td>2.349</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.566</td>
<td>0.689</td>
<td>0.626</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.610</td>
<td>0.567</td>
<td>0.618</td>
</tr>
</tbody>
</table>

Table 3 - Local and Global Integration values of Ard El Lewa settlement over 12 years
SYNTACTIC STITCHING:
Towards a Better Integration of Cairo’s Urban Fabric

Figure 6 - Axial Analysis of all the case studies in 2016
After completing the syntactical analysis, the results show different syntactical structures based on the original urban morphology. Planned settlements (Al Mohandiseen, Zamalek and Al-Sahafiyeen) have more highly integrated movement thoroughfares but also a higher standard deviation, indicating that there are areas that have a high level of movement, and areas that experience a low level of movement and thus decreased integration with the rest of the neighbourhood. This increased integration could be because the planned settlements are connected to the highways so there is an opportunity for the edge movement to occur.

The organic settlement (Mit Uqaba) has the lowest level of global integration but also the lowest standard deviation in both local and global integration, indicating that the neighbourhood is integrated as a whole but the highway cutting through it and the lack of connection to Al Mohandiseen prevents it from being integrated into the wider urban fabric. The informal settlements are between the planned and organic settlements in terms of integration.

In terms of local integration, all the settlements have similar maximum integration and the standard deviation has increased, indicating that even in the informal settlements there are areas that are not well integrated into the neighbourhood. This is reflected in the syntactic structure of the different neighbourhoods. The informal and organic structure is more centralised and there is little movement on the edge of the neighbourhood, forming an incomplete deformed wheel structure. In contrast are the planned settlements, which have strong edge movement and spokes, connecting the edges together. In informal and organic settlements, the highways surrounding them become hard edges, disconnecting them from the city and suppressing edge movement. In planned settlements (Al Mohandiseen, Zamalek and Al-Sahafiyeen), the highway acts as a connector since the settlements have access to the highway, promoting edge movement.
Looking at Ard El Lewa (fig. 7) shows the changes in the structure and integration that have taken place due to rapid growth. Due to the type of urban morphology, the growth was predictable, but rather than extending further outwards onto agricultural land, it is limited by the hard edge of the highway and so increases in density. In 2004, the structure was starting to extend outwards towards the edges, becoming more centralised in 2010 as the density started to increase and finally very centralised in 2016, the centre being the bridges that cross over the 26th July Corridor. While this may be the area that sees the most movement, it is also not a functional centre as technically it is where two edges meet.

Figure 8 - Map showing the Canals as they were in 1926 (a) (Source: Survey of Egypt) and the resulting highways in 2016 (b).
As well as the changing structure, the integration is decreasing as time passes. This is due to the increasing density of the settlement, which leads to decreased legibility from a visitor’s point of view. The settlement becomes less permeable and therefore less integrated; there are fewer movement thoroughfares due to the extremely long, linear grid. However, the standard deviation is decreasing, indicating that the neighbourhood is becoming more integrated as a whole rather than scattered areas that are integrated and areas that are segregated.

5. THE CANALS AS SUPER-GRID

If compared with the image of the canals and roads it is clear that the highways are built where old roads and canals used to be. There are two interesting observations:

1. The most integrated streets in the informal settlements (see fig 8) used to be canals
2. The most integrated streets in the planned settlements are ones that are connected to the highway system – which also used to be canals.

Following this analysis, it can be concluded that the canal system that existed in the early 20th century – used to irrigate the surrounding agricultural land – forms the basis of the “super-grid” that connects, or in this case disconnects, the city. This super-grid is reflected in both the planned highway system and the organically developed main streets in the informal settlements. Since the most integrated streets in the planned settlements are the ones that are connected to the super-grid, it can also be concluded that connecting the streets in the informal settlements to the highway grid (as was done in Ard El Lewa) will increase overall integration. Super-grids are usually created with the intention to create distinct neighbourhoods, only in this case the highways were created after the neighbourhoods with the intention to limit growth, becoming a boundary for separation rather than an interface for connection.

This creates an ‘incomplete’ super-grid that follows the pre-existing canal pattern but does not complete it, interrupting the connection between the local and primary streets (highways). The size of the super-block created by the highways super-grid varies between 1-1.6 km since the grid created by the highways is deformed and spaced at different intervals. Contrasting with this is the canal system in which there is more of a regular grid, on average 0.5km, since it is designed to connect all agricultural land to the water supply.

However, the rural plots that form the streets are very narrow which would mean that there would be almost 65 local streets inserted into one super block as it stands now.

6. STITCHING APPROACHES

In this analysis, one stitching approach was tested. The 26th July Corridor was connected to the informal settlements (where it had previously overpassed) and a direct link created to the main Ard El Lewa Street that was formed from a canal. Minor adjustments were also made, the main streets in the informal settlements were also widened slightly so they can be represented by one axial line and more local streets were connected to the super-grid. These interventions were considered minor and theoretically feasible in a real life scenario.

<table>
<thead>
<tr>
<th></th>
<th>No Highway Connection</th>
<th>Highway Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum</td>
<td>4.004</td>
<td>3.149</td>
</tr>
<tr>
<td>Average</td>
<td>1.760</td>
<td>1.696</td>
</tr>
<tr>
<td>Minimum</td>
<td>0.730</td>
<td>0.788</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.499</td>
<td>0.347</td>
</tr>
</tbody>
</table>

Table 4 - Integration values of the entire case study with and without the highway connection
The results indicate that movement is spread throughout the neighbourhoods, instead of being concentrated in one planned settlement. The increase in integration is most noticeable in the informal settlements, which are seeing emergence of edge movement and a stronger connection to the planned settlements. There is also lower standard deviation, which indicates that there are fewer areas of extreme segregation. Figure 9 shows the increase in integration in informal settlements, and much higher integration in areas that were previously extremely segregated.

Figure 10 shows the changing syntactical structure of the neighbourhoods before and after connection. After connection, the centre of the neighbourhoods has shifted to an equal location and spokes have started to emerge into the informal settlements, indicating the potential for the deformed wheel structure to develop with further connection and intervention. While the changes are not major, there is significant change in both the syntactical structure and integration values of the neighbourhoods.

Another approach that was considered involved aligning the streets in the informal settlements, but this proved to be difficult due to the misalignment of the initial base grid and the formation of T-junctions (fig 4) that the settlement followed.
7. CONCLUSION AND DISCUSSION

The canal system in Cairo was designed to be connected to the Nile and the agricultural land and be an integrative, equal opportunities system, providing irrigation to the land. With the rapid expansion of Cairo during the 1950s, the canals started drying up and left paths where they used to exist. Due to political pressures and a negative view of informal settlements, some of these paths were used to build highways that overpassed informal settlements and created a hard edge around them to prevent growth and promote segregation. Edge movement, which is vital to
consolidation into the main urban form, was supressed meaning that global integration and consolidation is not given an opportunity to form. The highways represent an ‘incomplete super-grid’ that does not create the necessary conditions for real superblocks to form, acting as a boundary to informal settlements and as a connector to planned settlements. In informal settlements, the main movement thoroughfares that emerged naturally are where the canals used to be, indicating that even though it was not planned, the canal system does in fact form the underlying global structure of this part of Cairo.

There are different approaches that can be taken to increase the integration of all settlements. The main approach would be completing the super-grid using the canal system that it’s based on, by using the main roads in informal settlements to link to the highway system, creating a regular super-grid and reducing the size of the super-blocks. Another approach would be promoting edge movement by increasing crossing points over the highways and incidence of local streets, tuning the relationship between the two grids as well as moving primary attractors to the edges. The super-grid can then be used to link the cores of the settlements and create edge movement, promoting a ‘deformed wheel’ global structure and increasing consolidation into the urban form, since syntactically they function well as discrete neighbourhoods. While one approach has been studied in this paper, further detailed study can be undertaken to determine the best stitching approach for different neighbourhoods. Further analysis is required before implementing such stitching approaches, and developing the Transformability index and route design (Karimi et al., 2007) has the potential for future scholarship.

The main limitation in this type of study is the accuracy and clarity of satellite imagery, especially historic imagery, which the analysis is based on. Care was taken to ensure that the maps are accurate and up to date in order to produce accurate results. Another limitation was the difficulty in analysing the super-grid because it is deformed and not spaced at regular intervals. This also means that it was not possible to compare it to similar super-grid analyses in other cities, but identifying the underlying structure of a deformed super-grid could be used to develop analysis tools to further the study of deformed, incomplete and naturally occurring super-grids. Using urban morphology as an analysis tool also highlights how super-grids can naturally occur, indicating that they are not just planned but rather can be an underlying system that actively shapes the morphology of the city.

The feasibility of implementing interventions should be considered, since prevailing negative attitudes against informal settlements means that it’s difficult to integrate socially between settlements, even though they may be physically connected. The nature of the highways may also need to be changed in order to connect them to the roads in the informal settlements, since they are designed for vehicular movement, not pedestrian. Thoroughfares that are parallel to the highways can be made, as well as increasing crossing points connecting the two sides together.
REFERENCES


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SPATIAL CONFIGURATION AND VEHICULAR MOVEMENT

A nationwide correlational study

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ABSTRACT

We provide the most comprehensive study to date on the correlation between network centrality measures and vehicular movement flows, using a model of the UK’s entire road network (2,031,971 nodes) and a very large dataset of vehicular movement counts (20,752 instances, evenly distributed over the UK’s territory). We describe the statistical associations between observed vehicular flows and the values of betweenness centrality of the road-network nodes where such flows were measured, the latter calculated using Euclidean and angular distance functions, across a number of increasing radii, from the local to the supra-regional scales. Relations to road capacity are also discussed in principal road networks where this is known.

The geographical comprehensiveness of our model and the size of our movement sample allows us to state, with unprecedented statistical validity, the clear outperformance of angular distance over Euclidean distance, on what concerns the effect sizes of the studied correlations. We also demonstrate the existence of two clearly different regimes of association between movement and centrality, occurring on the background and foreground networks of cities, which may be interpreted as new evidence of the dual structure of urban form, proposed by space syntax.

KEYWORDS

spatial configuration, vehicular movement, angular and metric distance, saturation

1. INTRODUCTION

The theory of cities that has emerged from space syntax studies (Hillier 2012, 2016), is grounded on two fundamental findings: the discovery of the deep relationship between the topological structure of urban spatial networks and the distribution of movement flows therein, which led to the concept of ‘natural movement’ (Hillier, Penn et al. 1993, Hillier 1996, Hillier and Iida 2005); and the identification of a number of geometric regularities specific of urban spatial networks that are directly related with their topological characteristics, which led to the proposal of the ‘dual background / foreground network’ model of urban form (Hillier 1999, Hillier 2002, Hillier, Turner et al. 2006).

The concept of natural movement states that, all other things being equal, the intensity of urban movement observed on a given space of the network will be proportional to the position of that space on the configurational hierarchy of the network; that is, proportional to the relative importance of that space in the web of connectivity relationships that the network creates.
Movement intensities, on their side, are determinant to the spatial location of urban functions, in that functions that benefit from public exposure (as commercial and other tertiary functions) tend to colonize movement-rich locations, while functions that do not (as the residential function) tend to occupy more secluded areas. The settling of movement-seeking functions in locations that are ‘naturally’ movement-rich (i.e. made so by their position on the network), generates a positive feedback loop, by the attraction that those functions exert on even more movement and on the further settling of similar functions. Cumulatively, the clustered functional pattern that we observe in cities emerges (Hillier 1996).

Space syntax has also dedicated close attention to the specific geometry of urban spatial networks. It was found that the lengths of axial lines possess self-similar properties, with the same proportion of few long lines to many short ones repeating itself at all scales (Hillier 2002, Carvalho and Penn 2004). But also, that long and short lines have distinct aggregation probabilities (Hillier 1999, Hillier 2002). Longer lines tend to aggregate sequentially, with each line linked to the following one at wide obtuse angles, forming a large-scaled web of multi-directional alignments. Shorter lines tend to form clusters in the interstices of that web, passing through or ending on each other at nearly right angles (Hillier 1999).

This probabilistic arrangement of urban grids has far-reaching topological implications. Indeed, it induces two strongly asymmetric connectivity patterns, because the length of axial lines is positively correlated with their connectivity (Hillier 1999). And because long lines are also much less frequent than short ones, the highly connected sequences that they form will tend to possess also relatively higher centrality levels, forming a large-scaled foreground network of main paths. While the much more numerous but less connected shorter lines, will have relatively lower centrality levels, creating a less differentiated background network. Most importantly, because of the asymmetry in their centrality levels, these two fundamental networks will have also different movement potentials – the foreground network carrying the bulk of urban movement, with the functional consequences mentioned before.

Through these two basic principles space syntax was able to propose a theory of urban form that links its topology, geometry and functioning, into a single explanatory framework. Such a theory is capable of making testable predictions, because it is based on specific morphological assumptions – such as the generic foreground / background model of urban form – which can be verified and potentially denied. As described in (Hillier, Turner et al 2006; Hillier 2012, 2016) the foreground network, which is the global structure that holds the city together and conveys the bulk of urban movement, has topo-geometric characteristics that make it a web of simplest paths (i.e. made-up of long lines with little angular variation), and not one of shortest paths (in the sense of those with less Euclidian length). A way of testing this proposition is to statistically compare the spatial hierarchies described by angular and Euclidean-defined centrality measures and the actual distribution of urban movement flows. If urban space is indeed globally hierarchized through topo-geometrical principles rather than by metric ones, the former hierarchy should describe better the actual distribution of urban movement than the latter.

Hillier and Iida (2005) conducted a correlational study of this kind, comparing the strength of the correlations between urban movement flows (vehicular and pedestrian) and two types of centrality measures (closeness and betweenness), defined under three types of distance functions – Euclidean (or metric), topological and a new angular function, which was designed to express the geometric properties described above. Although this work was carried out on localized urban areas and not at the scale of the entire city, the authors have provided convincing empirical evidence of the validity of the proposed angular distance function, as revealed by the stronger correlations between angular-defined centrality values and the observed movement flows. These results were followed closely by those obtained with topological-defined centrality values. However, in all of the studied cases, metric distance yielded the worst correlations both when applied to betweenness and closeness calculations, but particularly so in the latter case (Hillier and Iida 2005).
The adoption of the angular distance function for defining shortest paths when computing graph centrality measures, has since then become generalized in space syntax urban research. This is in strong contrast with other analytical approaches to urban spatial networks who do not rely on any specific morphological model and therefore assume that, insofar urban space has a hierarchy, such a hierarchy should be based solely on Euclidean distance relationships. Indeed, notwithstanding a few recent papers who acknowledge the relevance of the angular distance concept and apply it (Cooper, Fone et al. 2014; Gil 2014; Cooper 2015; Molinero, Murcio et al. 2015), most of the studies which resort to centrality indicators for describing urban spatial structure – as, for example (Crucitti, Latora et al. 2006, Scellato, Cardillo et al. 2006, Masucci, Smith et al. 2009, Porta, Strano et al. 2009, Porta, Latora et al. 2012, Strano, Nicosia et al. 2012, Strano, Viana et al. 2013) – still adopt Euclidean distance functions as a self-evident choice.

In this paper we readdress this disciplinary divide, through a correlational study similar to the one developed in (Hillier and Iida 2005). We will compare the strength of the statistical associations between observed vehicular movement flows and angular and metric distance concepts, in order to assess their methodological and theoretical value. However, due to the geographical comprehensiveness of the spatial network model employed here (the UK’s entire road network) and the size of the studied vehicular movement sample (20,752 count points), the detection of potential differences between the correlations obtained with the two types of distance will have unprecedented statistical validity. We aim at providing robust empirical evidence, capable of validating or denying the topo-geometric spatial structuring that space syntax proposes and, consequently, the theoretical constructs described above. Moreover, because we will do this at the scale of an entire country and in several geographical contexts (urban and non-urban), we also will test the potential generalization of such theoretical constructs from the urban scale to that of regional and supra-regional road networks.

2. DATASETS AND METHODS

2.1 THE ROAD NETWORK MODEL

The road network model used in this study is based on the Meridian 2 dataset (OS 2014), representing the full hierarchy of Great Britain’s road network, but not its absolute geometric constitution. Road representation is skeletal, collapsed into single road centre-lines (RCL) independently of the type of road or of its specific cross section (i.e. number of lanes or carriageways). All complex road junctions (e.g. roundabouts and motorway interchanges) are generalized as simple RCL intersections. The vector geometry of the RCLs themselves has been partially generalized through simplification, eliminating unnecessary detail while retaining their essential shape.
These characteristics make this dataset particularly fit to serve as a basis for syntactic models, because its level of representation very much approximates that of a typical syntactic segment map. Given its geographic extent, the model used in this study should be seen as exhaustive, for it comprises the full national road hierarchy. However, at the level of the finer-grained network of local streets and lanes, the Meridian 2 dataset has a certain degree of incompleteness. Therefore, centrality measures calculated under short radii of analysis should be expected to contain some noise, induced by local inaccuracies of the model. In its final state (Figure 1), the road network model has 2,031,971 segments, corresponding to a total segment length of 341,588 Km.

As in any syntactic segment model, individual line segments are encoded as the nodes \( V = \{1, \ldots, N\} \) of an undirected weighted graph \( G(V,E) \), in which any pair of nodes \( i \in V \) and \( j \in V \) are held to be adjacent, \( i \sim j \), when they correspond to segments that intersect on the segment map. The adjacency relations between nodes are encoded by edges \( (i,j) \in E \), if and only if \( i \sim j \).

Edges are weighted according to two types of distance cost – angular and Euclidean – denoted here respectively as \( w_a \) and \( w_e \). The angular distance cost between two adjacent nodes, \( w_a (i,j) \), is proportional to the angle of incidence \( \theta \) defined by the two segments encoded by \( i \) and \( j \), such that \( w_a (i,j) = 0 \) when the two segments are aligned and \( w_a (i,j) = 1 \) when the two segments make a right angle. Formally, the angular distance function may be defined as,

\[
w_a (i,j) = \frac{2\theta}{\pi}, \quad \theta \in [0,\pi[\]  

The Euclidean distance cost between two adjacent nodes, \( w_e (i,j) \), is the sum of the metric lengths of the segments encoded by \( i \) and \( j \), denoted \( l_i \) and \( l_j \), divided by 2; in other words, it is the actual length between the segments’ mid-points, measured along the segments in metric units. Formally, \( w_e (i,j) \) may be defined as,

\[
w_e (i,j) = \frac{l_i + l_j}{2}, \quad \{l_i, l_j\} \in \mathbb{R}^+  

These two distance functions serve to define the shortest paths (or graph geodesics) between each pair of nodes, in two different ways. Angular distance defines geodesics as those paths with minimal sum of angular change, Euclidian distance defines geodesics as those paths with minimal sum of metric length. Due to the high computational cost of determining minimal paths in large graphs and to the nationwide size of our network model, angular and Euclidean geodesics are calculated here for a number of restricted network radii. A network radius, defined here in metric units, induces a sub-graph around each node containing the nodes that are reachable from the origin node within the radius distance. It may be seen as the maximum trip distance from the node under calculation. In order to calculate centrality values under the two definitions of distance described above, we will use the following set of radii,

\[
R = \{1000, 2000, 5000, 10000, 25000, 50000, 100000, 150000\}  

Ranging from the local scale (i.e. 1Km), through the city scale (e.g. 10Km) and up to the supra-regional scale (i.e. 150 Km). The two distance concepts, angular and Euclidean, when applied to centrality measures, produce also different network centrality hierarchies in which a node may occupy quite different ordinal places. Here, we use the two types of angular and Euclidean defined geodesics, to compute the betweenness centrality (also called choice in space syntax) of each node $i \in V$, at each radii $r \in R$. The betweenness centrality of a given node $i$ is defined by (Freeman 1977) as,

$$C^B_i = \sum_j \sum_k \frac{n_{jk}(i)}{n_{jk}} (j<k)$$

Where $n_{jk}(i)$ is the number of geodesics between nodes $j$ and $k$ that contain node $i$ and $n_{jk}$ is the number of all geodesics between $j$ and $k$ (there can be several). Betweenness centrality quantifies how often a given node lies on the shortest paths between other nodes. From the point of view of vehicular movement on road-networks, it may be seen as a direct indicator of the traffic flow potential of a given node or, in our case, of a given road or street segment. The road-network model was processed in the network analysis software UCL DepthmapX (Varoudis 2012), for each of the two centrality measures, at each of the network radii mentioned before.

2.2 THE VEHICULAR MOVEMENT SAMPLE

Our vehicular movement sample is based on a publically available dataset (DfT 2014) describing annual average daily flows (AADF) of different vehicles types, at 22,758 count locations on the UK’s road network, distributed over the entire mainland territory. After several pre-processing operations, necessary for reasons of correct assignment of the count points to their respective locations on our road-network model, we have validated a study sample of 20,752 count points (91% of the original dataset).

These 20,752 count points are geographically evenly distributed (Figure 2), but their distribution per road class is neither random nor even. There are 12 road classes in the original dataset (Table 1), but the large majority of points (67%) are located on principal urban roads (PU, 40%) and on principal rural roads (PR, 27%), with all other 10 road classes representing only 33% of the occurrences. Thus, the sample has a strong bias towards principal roads and its direct use as such would certainly reflect that bias on the correlation results.

![Figure 2 - Geographical distributions of count points. From left to right: ‘all’, ‘motorways’, ‘urban roads’ and ‘rural roads’ (‘principal’ in red, ‘minor’ in green)
Table 1 - Original and aggregated road classification schemes.

<table>
<thead>
<tr>
<th>Original road class</th>
<th>Name</th>
<th>Frequency</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>Principal motorway</td>
<td>N = 18</td>
<td>Double-carriageway roads of strategic importance, with two or more lanes in each direction, whose maintenance responsibility lies with the local authorities.</td>
</tr>
<tr>
<td>TM</td>
<td>Trunk motorway</td>
<td>N = 778</td>
<td>Double-carriageway roads of strategic importance, with two or more lanes in each direction, whose maintenance responsibility lies with the local authorities.</td>
</tr>
<tr>
<td>PU</td>
<td>Principal urban road</td>
<td>N = 8213</td>
<td>A-roads lying in urban areas with a population of 10,000 or more, whose maintenance responsibility lies with the local authorities.</td>
</tr>
<tr>
<td>TU</td>
<td>Trunk urban road</td>
<td>N = 261</td>
<td>A-roads lying in urban areas with a population of 10,000 or more, whose maintenance responsibility lies with the central government.</td>
</tr>
<tr>
<td>PR</td>
<td>Principal rural road</td>
<td>N = 5637</td>
<td>A-roads lying outside urban areas, whose maintenance responsibility lies with the local authorities.</td>
</tr>
<tr>
<td>TR</td>
<td>Trunk rural road</td>
<td>N = 1566</td>
<td>A-roads lying outside urban areas, whose maintenance responsibility lies with the central government.</td>
</tr>
<tr>
<td>BU</td>
<td>Urban B-road</td>
<td>N = 485</td>
<td>B-roads lying in urban areas with a population of 10,000 or more.</td>
</tr>
<tr>
<td>CU</td>
<td>Urban C-road</td>
<td>N = 541</td>
<td>C-roads lying in urban areas with a population of 10,000 or more.</td>
</tr>
<tr>
<td>GU</td>
<td>Unclassified urban road</td>
<td>N = 1716</td>
<td>Local roads (mainly residential) lying in urban areas.</td>
</tr>
<tr>
<td>BR</td>
<td>Rural B-road</td>
<td>N = 670</td>
<td>B-roads lying outside urban areas.</td>
</tr>
<tr>
<td>CR</td>
<td>Rural C-road</td>
<td>N = 492</td>
<td>C-roads lying outside urban areas.</td>
</tr>
<tr>
<td>UR</td>
<td>Unclassified rural road</td>
<td>N = 375</td>
<td>Local roads (mainly residential but including rural lanes) lying in rural areas.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Aggregated road class</th>
<th>Name</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW</td>
<td>Motorways</td>
<td>N = 796</td>
</tr>
<tr>
<td>PU</td>
<td>Principal urban roads</td>
<td>N = 8474</td>
</tr>
<tr>
<td>PR</td>
<td>Principal rural roads</td>
<td>N = 7203</td>
</tr>
<tr>
<td>MU</td>
<td>Minor urban roads</td>
<td>N = 2742</td>
</tr>
<tr>
<td>MR</td>
<td>Minor rural roads</td>
<td>N = 1537</td>
</tr>
</tbody>
</table>

In order to mitigate that sample bias, we adopted the following re-sampling strategy. The original 12 road classes were aggregated into a simpler scheme of just 5 classes (motorways, principal urban and rural roads, minor urban and rural roads), which is the classification scheme adopted by DfT on their annual transport statistics reports (DfT 2016). After this operation, the sample was studied under progressive levels of disaggregation, starting with the full sample and ending on individual road classes (see Figure 4).

Besides the several types of road classes, the source dataset also provides AADF values for specific types of vehicles. These are “pedal cycles”, “bus” (i.e. buses and coaches), “two-wheeled motor vehicles” (i.e. bikes), “cars” (i.e. cars and taxis), “light goods vehicles” (i.e. vans), “heavy goods vehicles” (i.e. lorries) and “all motor vehicles” (i.e. all motorized vehicles aggregated). Given all these different vehicle types, we first want to see if they all have similar route choice behaviours or if they show differences on that regard. With that purpose, we select only those points where all types of vehicles are present [N=17,283] and we correlate their respective frequencies at each count point (logically, vehicles whose frequencies are highly correlated should have similar behaviours in terms of road network use). Such correlations are in general high, but they also show some variability. We thus run a principal component analysis (PCA) on those correlations, in order to identify the most relevant collinearity trends. We extract two principal components with eigenvalues higher than 1, describing two groups of vehicles whose frequencies are strongly associated. We determine the members of each group, by inspecting the loadings of the two principal components (i.e. their correlations with the frequencies of each type of vehicle), displayed on Figure 3.

Figure 3 - Loadings of the two PCs describing the associations between the frequencies of vehicles types.
The first component (PC1), which is responsible for almost all variance explained (70%), is highly correlated \( r > 0.9 \) with the frequencies of “cars”, “vans”, “lorries” and “all motor vehicles”; “bikes” are also strongly correlated \( r=0.77 \) with PC1. The second component (PC2), explaining only residual variance (16%), is highly correlated with the frequencies of “cycles” \( r=0.94 \) and, to a lesser extent, also with those of “bus” \( r=0.71 \).

We thus observe two opposed behaviours among vehicles’ route choices: one that may be represented by “all motor vehicles”; and another that may be represented by “cycles”, with a weak relationship \( r = 0.33 \) between their respective frequencies at each count point. We will therefore study the correlations between the AADF values of these two vehicle types and betweenness centrality values, while bearing in mind that “all motor vehicles” corresponds to 99.05% of the observed traffic, while “cycles” to only 0.95%.

### 2.3 ANALYTICAL AND STATISTICAL PROCEDURES

The sample was studied under progressive levels of desegregation accordingly to an analysis matrix (Figure 4), devised in such a way that each row corresponds to a specific hierarchical tier of the road-network (all, principal and minor roads) and each column to a specific geographical context (all, urban and rural). Each entry of the matrix corresponds to a different sized sub-sample, whose composition reflects its specific hierarchical and geographical contexts. When reading the matrix vertically, one can get a picture of the results by socio-demographic context (i.e. for the whole country, on cities and on rural areas). And horizontally, one may see how the results relate to the foreground/background-network model, previously identified and described in space syntax literature (Hillier, Turner et al. 2006, Hillier 2009, Hillier 2012). The sizes of ‘all motor vehicles’ and ‘cycles’ sub-samples differ slightly, because in the ‘cycles’ case...
we only consider the count points with non-zero frequency. Motorways \([n=752]\), because they are not classified either as urban or rural road-infrastructures, but also because they have very specific connectivity characteristics are left out of the analysis matrix and their results will be presented apart. For each of the sub-samples corresponding to each matrix entry (and for the motorways sub-sample), we will correlate the traffic flows and the network centrality values observed at each count location.

Both movement and centrality variables have highly right-skewed distributions, with many outliers, strongly deviating from bivariate normality. We will therefore use a robust non-parametric correlation method, namely Spearman’s rank correlation coefficient, denoted as \(\rho\) (rho). Spearman’s \(\rho\) is a measure of statistical association based on the ranks of two variables (i.e. on ordinal values indicating the relative magnitude of the actual values). Spearman’s \(\rho\) is particularly fit for our research subject, because we are not interested in the specific values of either movement or centrality, but rather in knowing which type of network hierarchy (as described by angular and Euclidean defined betweenness) better emulates the observed relative magnitudes of vehicular traffic flows.

Given the large size of our sample and sub-samples and the large effects encountered in this study, the significance level of the reported correlation coefficients is always \(p < 0.001\) (except on very few, identified cases). For all correlations, we also produce 95\% confidence intervals (CI). They indicate the interval around the correlation coefficient of the sample, where there is a 95\% probability of finding the correlation coefficient of the entire population of the correlated variables. CIs are important for visually comparing the differences between the obtained correlations (displayed in Figures 6, 8 and 9). When the confidence intervals of angular and Euclidean correlations don’t overlap, we can be sure with 95\% confidence that the difference between the two correlations is significant.

For each entry of the analysis matrix we will test the null hypothesis that the maximum correlation coefficients of angular-defined centrality and Euclidean-defined centrality with that movement sub-sample are equal (i.e. that the difference between the two maximum correlations will be zero). Our alternative hypothesis will state the opposite: that the maximum correlation coefficients of angular and Euclidean defined centrality will always be different (i.e. that the difference between both maximum correlation coefficients will not be zero).

Although previous research (Hillier and Iida 2005) points clearly to the prevalence of angular over Euclidean results, we do not specify a direction for our alternative hypothesis, because the large size of our sample dispenses the added power of one-tailed tests and we do not wish to make a priori assumptions which may result in the non-detection of negative differences.

Let \(\rho(A)\) be the Spearman’s correlation coefficient between observed vehicular movement and angular-defined centrality, and \(\rho(E)\) the coefficient between movement and Euclidean-defined centrality. We can formally define our null \((H_0)\) and alternative \((H_1)\) hypotheses as,

\[
H_0 : \max|\rho(A)| - \max|\rho(E)| = 0 \\
H_1 : \max|\rho(A)| - \max|\rho(E)| \neq 0
\]

The significance level for rejecting \(H_0\) will be \(\alpha=0.05\). In order to ascertain the actual significance of the difference \(\max|\rho(A)| - \max|\rho(E)|\), we will perform a specific test (Steiger 1980), implemented in the R package ‘cocor’ (Diedenhofen and Musch 2015), for the difference between two correlations obtained from the same sample (i.e. \(\rho(A)\) and \(\rho(E)\)) with one variable in common (i.e. vehicular movement flow). The result of the test is a z-score and \(H_1\) is two-tailed, so the critical value will be \(Z = \pm 1.96\) with \(p < 0.05\). Except for that specific test, all other statistical procedures and calculations were carried out in JMP Pro (SAS 2015).
3. RESULTS

We start by studying the correlations between the values of angular and Euclidean-defined betweenness, of the nodes where movement was observed (Figure 5). The objective is to assess the degree of association between the network hierarchies induced by the two types of centrality, along the scale of radii defined above, before asking which one better emulates observed movement. This is done for 5 different sub-samples, namely ‘urban roads’ (principal \( n=8,474 \) and minor \( n=2,742 \)), ‘rural roads’ (principal \( n=7,203 \) and minor \( n=1,537 \)) and ‘motorways’ \( n=796 \). All correlations are significant at the \( p < 0.001 \) level. Figure 6 shows the results on line charts, with the correlation coefficient \( \rho \) on the y-axis and the several analysis radii on the x-axis.

We note that the values of angular and Euclidean betweenness centrality are strongly positively correlated – very much so at local radii \( (\rho = 0.96, R = 2 \text{ Km}, \text{ on urban principal roads}) \) and progressive less at larger radii. Thus, the network hierarchies induced by the two types of centrality are actually very similar when short distances are concerned, but they diverge as larger parts of the network are encompassed.

An important qualitative difference is noticeable between urban and rural roads. In cities, the correlations of principal roads (i.e. of the foreground network) decay faster than those of minor roads (i.e. of the background network), implying a clear structural differentiation between those two road-classes along spatial scales. In contrast, in rural contexts, principal and minor roads follow rather close correlation curves, implying a lesser structural differentiation between road-classes. Finally, the motorway’s sub-sample shows a correlation curve that is similar to that of rural roads, but with an even stronger decay at large radii.
Figures 6 and 9 display on bar charts the results of the main correlation exercise carried out in this study, organized according to the analysis matrix described before. On these charts, light grey bars represent the correlation coefficients obtained with angular-defined betweenness centrality and observed movement at each radius, or $\rho(A)$; dark grey bars represent the correlations obtained with Euclidean-defined centrality and movement, or $\rho(E)$. The maximal correlations in each sub-sample are highlighted in red. All correlations are significant at the $p<0.001$ level, except for very few cases, identified by non-coloured bars. Error bars represent 95% confidence intervals.

We start by looking at the results of ‘all motor vehicles’ (Figure 6). The first thing we should note is that, for all sub-samples, the maximal angular correlations are always higher than the maximal Euclidean correlations (both highlighted in red) and well beyond the limits of confidence intervals. We can thus immediately state that, for the ‘all motor vehicles’ class (which, we recall, represents 99.05% of all observed traffic), $H_0$ is rejected for all sub-samples at the $p<0.05$ level, with all the tested differences being positive; i.e. $\rho(A) > \rho(E)$. Beyond their statistical significance, the actual differences between the maximal correlations are in general quite large (i.e. they have also practical significance). The mean of the differences $\max|\rho(A)| - \max|\rho(E)|$ for all samples is 0.126, with a maximal difference of 0.233 attained in ‘all rural roads’.
Also, the observed effect sizes are considerable, with \( \max \rho(A) > 0.7 \) in 7 of the 9 matrix entries.

<table>
<thead>
<tr>
<th>All roads</th>
<th>Urban roads</th>
<th>Rural roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>N = 19,952</td>
<td>N = 11,216</td>
<td>N = 8,740</td>
</tr>
<tr>
<td>max ( \rho(A) = 0.735 ), radius = 50 Km p&lt;0.001, 95% CI [0.728,0.741]</td>
<td>max ( \rho(A) = 0.739 ), radius = 25 Km p&lt;0.001, 95% CI [0.731,0.747]</td>
<td>max ( \rho(A) = 0.767 ), radius = 75 Km p&lt;0.001, 95% CI [0.758,0.775]</td>
</tr>
<tr>
<td>max ( \rho(E) = 0.614 ), radius = 50 Km p&lt;0.001, 95% CI [0.605,0.623]</td>
<td>max ( \rho(E) = 0.646 ), radius = 25 Km p&lt;0.001, 95% CI [0.633,0.655]</td>
<td>max ( \rho(E) = 0.534 ), radius = 50 Km p&lt;0.001, 95% CI [0.519,0.549]</td>
</tr>
<tr>
<td>( \max \rho(A) - \max \rho(E) = +0.121 ) Z = +36.608, p &lt; 0.0001</td>
<td>( \max \rho(A) - \max \rho(E) = +0.093 ) Z = +20.928, p &lt; 0.0001</td>
<td>( \max \rho(A) - \max \rho(E) = +0.233 ) Z = +38.959, p &lt; 0.0001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principal roads</th>
<th>N = 15,677</th>
<th>N = 8,474</th>
<th>N = 7,203</th>
</tr>
</thead>
<tbody>
<tr>
<td>max ( \rho(A) = 0.611 ), radius = 50 Km p&lt;0.001, 95% CI [0.709,0.725]</td>
<td>max ( \rho(A) = 0.498 ), radius = 75 Km p&lt;0.001, 95% CI [0.482,0.513]</td>
<td>max ( \rho(A) = 0.715 ), radius = 75 Km p&lt;0.001, 95% CI [0.704,0.726]</td>
<td></td>
</tr>
<tr>
<td>max ( \rho(E) = 0.503 ), radius = 25 Km p&lt;0.001, 95% CI [0.491,0.514]</td>
<td>max ( \rho(E) = 0.365 ), radius = 50 Km p&lt;0.001, 95% CI [0.347,0.383]</td>
<td>max ( \rho(E) = 0.502 ), radius = 25 Km p&lt;0.001, 95% CI [0.485,0.519]</td>
<td></td>
</tr>
<tr>
<td>( \max \rho(A) - \max \rho(E) = +0.108 ) Z = +20.299, p &lt; 0.0001</td>
<td>( \max \rho(A) - \max \rho(E) = +0.133 ) Z = +15.425, p &lt; 0.0001</td>
<td>( \max \rho(A) - \max \rho(E) = +0.213 ) Z = +25.837, p &lt; 0.0001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minor roads</th>
<th>N = 4,077</th>
<th>N = 2,742</th>
<th>N = 1,537</th>
</tr>
</thead>
<tbody>
<tr>
<td>max ( \rho(A) = 0.771 ), radius = 25 Km p&lt;0.001, 95% CI [0.498,0.543]</td>
<td>max ( \rho(A) = 0.777 ), radius = 25 Km p&lt;0.001, 95% CI [0.762,0.791]</td>
<td>max ( \rho(A) = 0.759 ), radius = 25 Km p&lt;0.001, 95% CI [0.737,0.780]</td>
<td></td>
</tr>
<tr>
<td>max ( \rho(E) = 0.698 ), radius = 25 Km p&lt;0.001, 95% CI [0.476,0.522]</td>
<td>max ( \rho(E) = 0.700 ), radius = 50 Km p&lt;0.001, 95% CI [0.680,0.718]</td>
<td>max ( \rho(E) = 0.673 ), radius = 25 Km p&lt;0.001, 95% CI [0.644,0.699]</td>
<td></td>
</tr>
<tr>
<td>( \max \rho(A) - \max \rho(E) = +0.073 ) Z = +11.961, p &lt; 0.0001</td>
<td>( \max \rho(A) - \max \rho(E) = +0.077 ) Z = +10.139, p &lt; 0.0001</td>
<td>( \max \rho(A) - \max \rho(E) = +0.086 ) Z = +8.629, p &lt; 0.0001</td>
<td></td>
</tr>
</tbody>
</table>

Figure 7 - Hypothesis testing of the results for ‘all motor vehicles’.

Figure 7 shows the actual z-scores and p-values of the Z test mentioned before (Steiger 1980); note the extreme positive values of Z (much higher than the critical value of Z=1.96) and the p-values always less than 0.0001, indicating the large differences observed and their high statistical significance. The consistency of these results across all sub-samples leaves no possible doubt that, at the scales where maximum correlations are attained (25Km, 50Km or 75Km), the network hierarchy described by angular-defined betweenness centrality emulates clearly better the actual usage of the road-network. These results strongly corroborate the findings of (Hillier and lida 2005), validating them at the level of an entire country and within several of its geographical contexts.
The ‘motorways’ sub-sample produces similar results (Figure 8). The gap between the maximum correlations obtained with the two types of centrality is now even more clear, with angular-defined centrality attaining a coefficient ($\rho = 0.6$) that is more than twice that of Euclidean-defined centrality ($\rho = 0.237$). Therefore $H_0$ is again rejected without ambiguity. The radii at which these maximal correlations are attained (150 Km and 100 Km, respectively), as well as the clear negative correlations at local radii (1 Km and 2 Km), are consistent with the long-distance vehicular movement that motorways convey.

Finally, we look at the correlation results for the ‘cycles’ class of vehicles (Figure 9), which show a very different pattern. The first obvious observation, is that the previous large gap between angular and Euclidean correlations has vanished. In several sub-samples, the maximal Euclidean correlations are now slightly higher than the angular ones. Maxima are now attained at 5 Km and 10 Km (25 Km in just one case), with correlations decaying fast afterwards (especially angular ones), reflecting the more localized range of cyclists trips. From the most local scale (1 Km) until the scales at which maxima are attained (5-10 Km), the differences between correlations are very small and with a general overlap of confidence intervals. Their significance cannot be assessed visually on the graphs, so we rely on the Z test for the difference between maximal correlations (Figure 10).
We fail to reject $H_0$ in three cases, because there is no significant difference between the maximal correlations. We can reject $H_0$ in six cases; of these, two have significant positive differences (i.e. the correlation with angular-defined centrality is higher), but in the remaining four cases the differences are actually negative (i.e. the correlation with Euclidean-defined centrality is higher). Nevertheless, all the differences are small; it is the large sizes of our sub-samples that are capable of producing statistically significant results. However, statistical significance is not the same as practical significance. A difference of just $|0.032|$ between correlation coefficients (the maximal significant observed difference for ‘cycles’, in ‘all rural roads’) has little or no relevance to the relative descriptive power of the two centrality measures. Thus, in this case, we cannot conclude for the superiority of any of the two tested definitions of betweenness centrality. Rather, we must note that the observed differences between the correlations of the two centralities types with the frequencies of ‘cycles’, have little practical significance and may be considered inconclusive.
Figure 11 summarizes the results of the overall correlation exercise, expressed as the values of the difference $\max|\rho(A)| - \max|\rho(E)|$, for each of the studied sub-samples; it also shows 95% confidence intervals for those differences, computed according to the procedure proposed by (Zou 2007) and implemented in (Diedenhofen and Musch 2015). The ‘all motor vehicles’ class (99.05% of the observed traffic) produced unambiguous positive correlation differences, for all sub-samples (mean of +0.15); whereas the same differences for the ‘cycles’ class (0.05% of the observed traffic) were less stable and much weaker, oscillating around zero (mean of -0.007) on the several sub-samples.
4. DISCUSSION AND CONCLUSIONS

4.1 ALL MOTOR VEHICLES

In all geographical and road-hierarchical contexts represented by our analysis matrix (i.e. from the whole UK’s road-network to individual road-classes of urban and rural areas) and at the radii where the maximal correlations were attained, the network hierarchy induced by angular-defined betweenness centrality did emulate clearly better the actual usage of the network itself. However, the interpretation of this in terms of the drivers’ cognitive reading of the geometric properties of the network, as proposed in (Hillier and Iida 2005), remains uncertain. It is however clear that angular shortest paths are also the simplest paths, i.e. those encoding the minimum amount of information (Rosvall et al. 2005). Thus, what we can state with renewed confidence, is that the space syntax prediction that road networks are hierarchized by information minimization principles (i.e. that simpler, thus straighter, network paths will correspond to more used streets and roads), is now supported by strong evidence. And that the network hierarchy induced by prioritizing paths by their least Euclidean lengths, has a clear weaker association with the observed movement intensities. The informational content of road-networks, whose morphological manifestations have since long been identified by space syntax (Hillier 1999, 2002, 2005), seems therefore to be an unavoidable and fundamental property of these objects, which can no longer be sidelined by ignoring the relevance of angular network distance.

But our results also shown that Euclidean properties should not be sidelined either. If we look again at Figure 6, focusing on the trajectories of the correlations’ values along the analysis radii, we note that at the most local radius (1 Km) and in almost all sub-samples, and even though both correlations are low, Euclidean-defined centrality is in general stronger. The divergence between the correlations of the two types of centrality becomes unquestionable only after R=10 Km, when angular yields always higher correlations. Looking at Figure 5, one can also see that that is the radius at which the values of angular and Euclidean-defined betweenness centrality start to clearly diverge, after their strong initial correlation. Thus, even if the higher relevance of angular-defined centrality at the city-scale and beyond (i.e. R>10 Km) seems undisputable, our results also show a clear (albeit weak) signal that Euclidean structural principles are important at local scales; a fact already acknowledged in (Hillier 2006).
We also note that the differences between the values of the two correlations are clearly larger in ‘principal roads’ (which correspond to the foreground network) and narrower in ‘minor roads’ (corresponding to the background network). This is in strong accordance with the specific topogeometrical properties of each of those generic networks, as described in (Hillier 2006); given its angular-minimizing morphology, we should expect the results on the foreground network to be particularly expressive, regarding the superiority of angular over Euclidean distance.

And indeed this is what happens. However, this effect is actually more pronounced in rural than in urban roads (see Figures 6 and 11). This needs an explanation, because one would also expect the differences between the geometries of the foreground and the background networks to be stronger in cities, where they were identified in the first place. In Figure 12 we show two scatterplots, of the ‘all urban’ and ‘all rural’ sub-samples, with angular-defined betweenness centrality values (R=75Km) on the x-axis, and ‘all motor’ vehicles AADF values on the y-axis (values are logged on both axes); minor roads are represented by red points and principal roads by blue points. Because of the noise in data, we fit a local kernel smoother (black curves) to each plot, in order to highlight the main trends in the clouds of points.

What we see when looking at Figure 12 is that there is a striking qualitative difference between urban minor and principal roads, that is not present in rural roads. In rural roads, the bivariate relationship between centrality and movement is linear. In other words, in all rural roads (minor and principal), more centrality means on average always more movement. But in urban roads, the average slope of the fitted curve is not the same for minor and principal roads (it is clearly lower on the latter group). This means that, in cities, from a certain threshold on, further gains in centrality will result only in marginal gains in movement. This is a clear sign of a saturation effect – a sudden and sustained decrease in the rate of response of one variable regarding the other. And the saturation threshold coincides with the minimum centrality level of principal roads; or, in other words, of the foreground network.

The saturation pattern for urban roads shown on Figure 12, may be seen as a signature (both structural and functional) of the dual generic morphological model of cities, proposed by space syntax. Such pattern implies that there is a sudden change from a system where low movement intensities increase gradually with centrality – that is, the background network; to another system where centrality is high, but where there is always lots of movement, with a more uniform intensity and least dependent of (thus, least correlated with) centrality variance – that is, the foreground network. Moreover, this effect is entirely absent in rural areas, providing also a very suggestive image of the intrinsic structural and functional differences between urban and rural road networks.
The lower dependence between the variances of movement and centrality in the foreground network of cities explains the lower correlations detected in the ‘principal urban’ roads subsample (see Figure 6). Indeed, notwithstanding the high movement intensities observed on those roads, the direct relationship between movement and centrality partially breaks down there, as if another variable was constraining it. We suggest this to be an effect of the spatial constraints that exist on cities, namely regarding existing road capacities and their potential increase.

We further explore this hypothesis with another dataset (DfT 2017), containing the width of the space available for vehicular circulation of principal roads (both urban and rural), at each count location of the main dataset used in this study (see endnote 1). We use multiple regression to study the inter-dependencies and relative importance of three factors, for predicting observed movement in urban and rural principal roads (Figure 13). These three factors are: Euclidean-defined betweenness centrality at radius 75 Km (noted as BCm75k, in Figure 13), angular-defined betweenness centrality at radius 75 Km (noted as BCa75k) and local road capacity (noted as Width).

Figure 13 reports the results of eight hierarchical OLS regression models, describing the impact of each movement predictor, in urban and rural principal roads. Each variable is inserted sequentially (i.e. hierarchically) into the models (see column ‘Step’ on Figure 13), in order to observe the change in two parameters: the standardized β coefficient (measuring the effect of each predictor on the dependent variable); and the change in R² (ΔR²) when a variable is inserted last in the model (corresponding to its individual contribution in terms of explained movement variance, while controlling for the variable inserted first).

<table>
<thead>
<tr>
<th>Principal urban roads</th>
<th>Principal rural roads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>Model 1</td>
</tr>
<tr>
<td>Step</td>
<td>Variables</td>
</tr>
<tr>
<td>1</td>
<td>Width</td>
</tr>
<tr>
<td>2</td>
<td>Width</td>
</tr>
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<td>1</td>
<td>BCa75k</td>
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<td>1</td>
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</tr>
<tr>
<td>1</td>
<td>BCm75k</td>
</tr>
<tr>
<td>2</td>
<td>BCm75k</td>
</tr>
</tbody>
</table>

Figure 13 - Multiple-regression models, exploring the variances explained (ΔR²) by each of the movement predictor variables (BCa75k, BCm75k and Width), while controlling for the others.

Euclidean-defined centrality is always a worse movement predictor than road capacity, both in urban and rural principal roads (models 1.4 and 2.4, respectively). The same is not true for angular-defined centrality. Although in principal rural roads angular is capable of explaining more variance than width (model 2.1), the situation is inverted in urban principal roads, with width playing a more important role (model 1.2). We see then, that in the foreground network of cities (i.e. on urban principal roads), the relationship between spatial centrality and movement is constrained by existing road capacity.

We must bear in mind that movement potential, as expressed by network centrality, is a more primitive and more fundamental characteristic than road capacity. Intuitively, one would expect the latter factor to be determined by the former and this must indeed be so, if no other spatial constraints are present (as it is the case of rural settings). However, urban space is by definition scarce and urban streets, when completely delimited by buildings, create very strong limits to increases in road capacity. We thus provisionally propose that the saturation pattern shown
on Figure 12, is the product of the spatial constraints characteristic of cities, which impose restrictions on the direct centrality / movement relationship.

This new insight, which is only touched upon here, will be theme for further research. But the finding of the foreground network’s saturation regime sheds new empirical light on the dual model of urban form proposed by space syntax. It shows that the foreground network, more than just a main web of movement, may be seen as a whole phenomenon on its own right, highly differentiated from the rest of the city, both functionally and structurally.

4.2 BICYCLES

Despite the much smaller representativeness of the ‘cycles’ vehicular class regarding the overall observed traffic (0.05%), we have found that that class of vehicles produced a very different correlation pattern with the two types of centrality studied. In contrast with the remaining observed traffic, cycles yield very small differences between the correlations with Euclidean and angular-defined centrality, which in some cases were actually non-significant. Such an undifferentiated behaviour demands of course some reflexion.

Previous space syntax studies addressing cyclist flows have found significant correlations with angular-defined centrality indicators, but always in conjunction with other variables in multiple regression models. Studying cycles flows in two central London local areas, (Raford, Chiaradia et al. 2007) report significant correlations of $R^2=0.67$ and $R^2=0.76$, with angular-defined closeness centrality combined with segment length and a dummy variable representing the presence of cycling lanes. Also in a London local area, Law, Sakr et al. (2014) report a coefficient of $R^2=0.66$ for normalized angular-defined betweenness also combined with the presence of cycling lanes. However, these two studies do not contemplate the option of introducing Euclidean-defined centrality measures in their models. Cooper (2017) uses a complex version of network distance, including Euclidean and angular distance factors mixed with road slope and traffic volumes, for calculating betweenness centrality on Cardiff’s entire street network. The author reports a maximum association of $r=0.78$ ($R^2=0.61$), between the composite betweenness centrality measure and observed cyclists flows.

Although the results of these studies are hardly comparable in numerical terms, we note that the range of the detected effect sizes is similar ($R^2 = 0.7$). In this paper, the maximum effect sizes observed for the ‘cycles’ class of vehicles were $\rho (A) = 0.72$ and $\rho (E) = 0.73$, at radius 5Km, in the ‘all principal’ roads sub-sample. This coefficients are lower than the ones cited before (as they are not squared), but our sample is also much larger. Also, we use simple bi-variate correlations and not multiple regression models (which naturally yield higher correlations, due to the presence of multiple factors). But the main difference is that the above mentioned studies do not compare the performances of angular and Euclidean-defined centrality and thus do not provide information on that regard. Our main finding regarding ‘cycles’ does not concern the size of the maximal effects obtained with angular and Euclidean-defined centralities (which were large, at any rate), but rather the fact that the differences between such effects were negligible. Actually, there is no obvious reason to assume that cyclists would behave exactly in the same way as the generality of motorized vehicles.

Indeed, discrete choice modelling of cyclists’ route preferences (Menghini, Carrasco et al. 2010; Broach, Dill et al. 2012) shows that cyclist route choice is highly idiosyncratic and influenced by many factors. Euclidean distance seems to be by far the most important negative factor, followed by a clear aversion for high traffic volumes and strong slopes. However, cyclists are also quite sensitive to turn frequency, preferring simple routes. Our results seem to be in line with these findings, with Euclidean distance postdicting marginally better the observed cycles flows, but being followed very closely by angular distance. We suggest that the minimal differences observed between the two distance types should reflect the overlap of the negative and positive route choice factors mentioned above.
However, given the relative incompleteness of our network model at the most fine-grained scale, and also given the relative spatial sparseness of the count points of the movement sample used here, we cannot deem our results conclusive for the ‘cycles’ vehicular class. Indeed, in the space syntax studies reviewed above (except Cooper 2017), the spatial distributions of the count locations were highly dense (as they covered local urban areas), with count locations on almost every street segment. These enhanced sampling densities can produce results different from ours, because cyclist movement (in contrast with that of motorized vehicles) is prone to follow less stable (or more unpredictable) routes, in the sense of not being altogether constrained to the spaces of motorized vehicular circulation. As it is the case of pedestrian movement, the study of cyclists’ movement might depend on high spatial resolution samples, which is not the case of the sample used here. In this sense, the inconclusiveness of our results regarding cyclists’ movement, clearly points to the need to investigate this theme more intensely, in order to understand the true roles of angular and Euclidean distance, in the movement patterns and route choice strategies of cyclists.
ENDNOTES

1  This dataset was obtained by personal communication (Richard German, October 28, 2016), through the email address ROADTRAFF.STATS@dfi.gsi.gov.uk.

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BUILDING AN INTEGRATED URBAN MODEL PLATFORM:
The case of the City of London

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ABSTRACT
Cities are comprised of many interconnected and overlapping systems; so analysis and management of cities should be approached holistically. The city is primarily for people, thus the analysis, planning, and design of cities should focus on the outcomes that affect the lives of the people that use them.

To explore the potential of a holistic, multidimensional approach, an Integrated Urban Model (IUM) concept was previously developed to create spatial strategies for Jeddah, Saudi Arabia (Karimi, Parham and Acharya, 2015). The IUM used spatial network models weighted by estimated land-use based trip generation/attraction values to appraise proposals for development; this utilised the principal of Origin-Destination Weighted Choice (Karimi, Parham, Friedrich and Ferguson, 2013) to weight segment choice by the origin and destination values of paths that pass through it. The IUM approach allowed the impact of land use and spatial configuration to be assessed within one model, providing a clearer view of how people interact with space than modelling each element individually.

The IUM concept from the Jeddah project was built upon for the City of London Corporation to become a long-term framework for multi-dimensional holistic urban modelling; forming a key planning and design tool that can adapt to new ideas and datasets. The paper outlines the general framework of an Integrated Urban Model, before exploring how this framework was used in real-world practice for the City of London’s pedestrian movement model.

KEYWORDS
Planning process, sub-regional plans, integrated urban models, weighted space syntax analysis, planning option testing, densification.

1. DEVELOPING AN INTEGRATED URBAN MODELLING FRAMEWORK
The IUM platform is built around the spatial network of the area. This forms the foundation of the analysis; all other data layers are aggregated or disaggregated and translated to link with the spatial network model.
The spatial network model on its own allows certain key network properties to be calculated, including:

- Betweenness Centrality/‘Choice’ (Angular cost)
- Closeness Centrality/‘Integration’ (Angular cost)
- Metric catchments (Metric cost)

Land use and transport data are key data layers to integrate with the spatial network model, as these are the most significant drivers of activity, along with the spatial configuration of spaces. The potential for further holistic analysis is enhanced when other data layers are carefully integrated and linked to the platform. For example, census data can be used to assess how spatial configuration and land use patterns in neighbourhoods relate to residential travel behaviour. A site allocation for employment land uses can be assessed based on access to residents with certain skills and the impact of development proposals on pavement crowding risk can be evaluated.

A key to providing meaningful insight to such holistic systems is to translate complex multi-system relationships into human-based outcomes. How do different systems in a city influence people and vice versa? Do plans increase or decrease the quality of life? Does a city allow opportunities and choices for people in work and leisure?

In practice, using an IUM can be more than a simple model. Maintaining a persistent IUM framework with up to date data can perform as a hub for urban data and analysis for many disciplines, supporting interlinked urban planning and design and policy decisions with a suitably multi-dimensional approach. An IUM framework was built for the City of London and provided a useful opportunity to test and develop the methodology in practice.

2. CASE STUDY - CITY OF LONDON PEDESTRIAN MODEL

For the City of London Corporation, a district-wide model was commissioned to analyse and forecast pedestrian movement at a strategic level in the City. The model is designed to be a key input and assessment tool for strategic planning and city management duties such as the Local Plan, Development Control, Urban Design, Air Quality, and Highways. The key focus of this model was testing the impacts of developments and transport changes on pedestrian movement patterns and levels, including a predictive model for a future scenario of 2026, assisting the City in developing their future planning strategy.

Given that pedestrian movement was the key metric, the currency with which the layers in the model interacted is the unit of people. All elements of the model were converted where possible into matching measures of people flow (per hour or another time period); this ensured that the input and output were directly relatable to human-based outcomes.

Each address point unit or transport stop was assigned an estimate of people entering and exiting for the model periods. Where available, this was estimated based on land use and floor space figures, as well as using research on the trip generation characteristics of certain land uses.
The land use and transport origin and destination values were assigned onto their closest spatial segments. The angular choice values are then calculated based on various radii of metric distance for comparison. The calculated choice values on each spatial segment were multiplied by the weight of the origin and destination values of the journey passing through a segment (Karimi et al 2013). This integration of models combines the movement potential of a street by virtue of its network connectivity and the movement potential of a street by virtue of its location on the shortest path between modelled land uses.

This model output was validated against historic pedestrian movement data collected through a number of pedestrian movement surveys undertaken over a 5 year period for Space Syntax’s various previous projects. The best fitting choice radius for the spatial network analysis was assessed based on the relationship with the recorded movement data. On balance the integrated weighted choice value tended to relate more strongly to pedestrian movement than the basic spatial choice value, suggesting that the land use/transport influence is a significant element in assessing pedestrian movement potential in cities.

It is important to note that the dataset was limited in sample size at around 400 locations, did not cover the entire street network evenly, and had a significant variation in survey dates. Therefore there was an inherent limit in the accuracy of the recorded data and its representation of reality, which in turn limits the accuracy of any correlation or calibration.

Given the limitations, the model still provides a new insight into the strategic hierarchy of spaces in the City of London, the key being its ability to respond to land use and transport changes. Due to its ability to predict, the model was used to develop a future forecast model for the year 2026. Land use and spatial network changes were modelled based on planning application data. Changes in transport entry and exit volumes were estimated based on a general estimate for future population uplift.

The example in Figure 2 demonstrates how the IUM reveals the result of multiple cumulative impacts; Bishopsgate is predicted to experience increased pedestrian movement due to both the proximity to the cluster of high-rise developments and the spatial importance of Bishopsgate as a route between new developments and major destinations such as Liverpool Street station and Bank. Using the model the City can better plan for and manage this impact through their various responsibilities and duties, such as changing height limits, land use balances, urban design and street improvements amongst many others.

The model was built almost entirely on secondary data; including desktop study, existing mapping data, government records and survey data. However, the model still manages to be
a very useful and legible indication of how the City of London’s streets and spaces are used by pedestrians now and in the future. This strong foundation can be built upon by collecting high-quality primary data on pedestrian movement, land use, and other human behavioural metrics to bring more resolution and accuracy to the model.

Since the IUM is a set of discrete but linked layers of data and models, it is flexible and capable of taking on new information and data as it becomes available. Ongoing development of the City’s IUM includes assessing pavement capacity against the model’s predicted increase in pedestrian movement, identifying risk areas that require more detailed study. The framework can therefore also be a starting point, providing high-level indications for the need for detailed studies and projects, ensuring that limited funding and resources can be allocated on the basis of objectively-assessed risks and opportunities.

A comprehensive IUM provides a clarity and authority which can cut across complex and subjective interactions concerning how space is developed and used. The positive and negative externalities of decisions can be estimated in a standardised and legible way, ensuring a fairness and reliability for stakeholders, building trust, increasing cooperation and understanding and improving planning and policy process outcomes for people.

3. CONCLUSION – OPPORTUNITIES OF IUM FRAMEWORK

The IUM framework is an ideal way of tying together many separate but linked dynamics of the city. It can simply enhance the insight of space syntax analysis, but it can also become a comprehensive framework that links the interactions of various urban systems. Through analysis and research the IUM can help assess the human-oriented outcomes of planning and designing these urban systems. The City of London is now utilising this methodology in their day to day planning and management for one of the most dense and economically active areas of London.

Urban data such as land uses, transport journeys and censuses are becoming more open and readily available. Use of mobile phone or automated sensors can bring a systematic overview of human movement patterns, refining theories of spatial interaction and increasing the confidence in predicting and planning.

Rapidly advancing open source technologies, including OpenStreetMap, Spatial Databases and GIS, make construction of such models relatively fast, transparent and straightforward. Development of software which can collate, combine and integrate disparate data layers into models is ongoing, and offers the chance for the IUM framework to respond more quickly to new theories, discoveries and realities while retaining a central legibility and link to human outcomes.

Information taken from the model is never isolated to one topic and will always allow a user to understand how one element affects the other. By integrating different elements of cities, it also integrates different disciplines (Figure 3), allowing holistic planning to truly be utilised in a multi-dimensional context.
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