How is multiscale accessibility related to population, functional and socio-economic characteristics of settlements: the case of Israel

Abstract

Accessibility is a basic and well-known term in urban and regional planning and has significant influence of settlement performance. Accessibility analysis done so far mainly with focus on cities and metropolitan areas, but less attention was given to their accessibility as part of the national system. Although recent studies have been referred to accessibility at various spatial scales, the investigation was done for accessibility patterns at different scales, with no reference to the accessibility level of individual settlements over these scales. Our study aimed to examine multiscale spatial accessibility of individual settlements at the nationwide settlement system of Israel and to clarify how it related to the settlements performance concerning population, functional and socio-economic characteristics. Using the space syntax methodology, spatial accessibility was analyzed for the entire national road network of Israel across different geographic scales – from local culminating in the national scale. The results expose three differentiated spatial system - local, regional, national according to the correlation between accessibility level across scales. According to this, eight multiscale accessibility profiles at the settlement level were determined in order to represent different level of accessibility at different spatial systems exposed. We found that multiscale accessibility strongly related to settlement performance and pervasive accessibility across spatial scales may improve settlements performance.
Keywords: multiscale accessibility, space syntax, national road network, settlement performance, Israel.

1 Introduction

Accessibility is a basic and well-known term in urban and regional planning. Many definitions have been proposed (Geurs & van Wee, 2004), but a simple one refers to the "*relative nearness or proximity of one place or person to all other places and persons"* (Batty, 2009, p. 191) where the term of places also includes opportunities and activities. Accessibility of a place is inherently related to its functional, economic and social aspects (Geurs & van Wee, 2004) with significant potential effects on land use change (Susilo, 2017) and future potential development (Wachs & Kumagai, 1973).

Previous studies have analysed accessibility in specific contexts or for a specific area, usually up to the city or to the metropolitan level (e.g., Benenson *et al.*, 2011) without explicit reference to the larger context as part of a national system. However, cities are indeed an integral and critical part of regional and national contexts which can greatly affect city performance (Law & Versluis, 2015; Serra, Hillier & Karimi, 2015). Although recent studies at regional and national scales have been refers to accessibility at various of spatial scales (Serra & Pinho, 2013; Parham, Law & Versluis, 2017), no attention has yet been given to the settlements accessibility level across spatial scales (i.e., multiscale accessibility). In other words, we can describe the accessibility analysis done so far as investigation of accessibility patterns at different scales, with no reference to the accessibility level of individual settlements over these scales.

An examination of the multiscale accessibility of settlements may stand in line with the theory of *pervasive centrality* of cities, according to the effect of centrality functions diffusing throughout the urban grid at all spatial scales with a strong spatial correlation. Thus, according to this perspective the accessibility and centrality analysis is more complex than traditional analysis of accessibility patterns at defined spatial scales (Hillier, 2009; Omer & Kaplan, 2018). Therefore, characterization of settlements/ locations accessibility at different spatial scales may assist planning considerations at the local, regional and national levels.

Our study aimed to examine and to represent spatial multiscale accessibility of settlements across geographic scales, and to clarify its relationship to population size, functional and socio-economic characteristics in the nationwide settlement system of Israel.

2 Methodological framework

The methodological framework implemented in this paper includes three main stages: the first aimed to analyses the accessibility potential at different spatial scales and detect the emergence of different spatial systems; the second aimed to reveal categories of settlements according to their multiscale accessibility levels by different spatial systems; the third aimed to examine settlement performance associations according to multiscale level of accessibility.

2.1 Case study

This study was carried out in the nationwide settlement system of Israel. Israel is a small country (size of 22,072 km^2, 8,797,900 citizens), densely populated (387/km^2 in all land area and 7,117/km^2 in the built-up area) with a developed economy characterized by high urbanization levels and a rapid history of development (ICBS, 2018). The research was included two main data sources: (i) GIS layers of the Israel road network obtained from GISrael (a geographic information database in Israel, a product of the Mapa Company), and (ii) the most updated available official data at the settlement level of population, employees, commuters and socio-economic index (ICBS, 2008a,b,c).

2.2 Natioanl road network model

Road networks are the basic elements that allow accessibility connecting places from the small scale (neighbourhood/settlement) through the medium (cities) to the regional and national scales (Parham, Law & Versluis, 2017; Serra & Pinho, 2013). Based on Space Syntax methodological framework, a set of theories and techniques for topo-geometric analysis of spatial configurations across different geographical scales (Al Sayed *et al.*, 2014), we analyzed accessibility levels across various geographic scales for the entire Israel state.

The road network in Israel is a kind of “island state”, without continuity to surrounding countries. The national road network model used here is based on the entire national paved road network. Road representation is skeletal where the original road network was transformed into Road Center-Lines (RCL) based on different road types. Following this, their geometries were simplified in order to reduce unnecessary complexity, as suggested by Krenz (2017), and have been performed in similar ways for several national-scale studies (e.g., Parham, Law & Versluis, 2017). These steps of processing were done in the ArcGIS (ver. 10.3) software. This process transformed the road network into road segments which was found to be consistent with the results of the “traditional” Space Syntax segment line model (Krenz, 2017). The final network model included 333,303 nodes (road segments).

Subsequently, we analyzed the spatial configuration of Israel’s road network based on angular segment analysis (the cumulative angular changes made along a route), which has been found most suitable for detecting spatial patterns at the urban, regional and national scales (Hillier, Yang & Turner, 2012; Serra, Hillier & Karimi, 2015; Serra & Pinho, 2013). In order to examine the spatial accessibility in Israel, we use the centrality measure of *Integration*, which corresponds to the graph-based *Closeness* centrality measure. This measure describes how close a given node (road segment) is to all other nodes representing the degree of accessibility for each road segment in the entire network (radius N) (Omer & Jiang, 2015). Formally, the closeness measure is defined by:

$$(1) \quad Closeness\,(Vi) = \frac{n-1}{\sum_{k=1}^{n} d\,(Vi, Vk)}$$

where n is the total number of segments (nodes) within a road network and d is the shortest angular distance from a given road segment *(Vi)* to every other road segments *(node Vk)* in the segment map. The integration measure was also calculated for spatial scales with radii of 1, 2, 5, 10, 15, 30, 50, 75, 100 and 150 km, in order to represent a full range of geographic scales. The calculation of integration centralities was done using Depthmap software (version 10.3, UCL).

2.3 Multiscale accessibility analysis

In order to exam the spatial configuration of multiscale accessibility we implemented three kinds of examinations. The first, examines the correspondences between accessibility levels in different geographic scales (metric radii) at the road segment level, according to the correlation between integration values across scale for each road segment in the network. This enabled the detection of differentiated spatial systems.

The second, aims to reveals the multiscale accessibility level of the settlements, that is the accessibility level of each settlement in the spatial systems that were defined in the first test. The average integration value for each settlement was calculated by taking the mean integration value of all road segments in each settlement’s polygon, similar to other studies (Law & Versluis, 2015; Serra, Hillier & Karimi, 2015). The mean integration was calculated for all designated spatial radii. Following this, the principle of high/low clusters to characterize the level of accessibility of a settlement (high or low) was used to determine the accessibility profile of settlements across all examined radii. Since accessibility level of settlements for local and regional scales are characterized by heavy-tailed distributions, we apply the classification technique of the *head/tail break*s that deals with a heavy-tailed distribution, thereby categorizing the data into “head” (values above mean) and “tail” (values below mean) (Jiang, 2013). Appling this algorithm for each accessibility value over all examined radii resulted in two groups for each scale: the *high*- settlements with accessibility level above the mean, and the *low*- settlements with accessibility level below the mean. Then, we summed the score of *high/ low* accessibility level for each examined scales for all settlements. The resulting process classified all settlements into eight *multiscale accessibility profiles* (2^3- high or low in three spatial systems) according to their accessibility across all geographic scales. For example, a settlement with “high” levels of accessibility at all spatial system radii (see section 3.1) gets a profile of “HHH”, i.e., high level of accessibility in the three spatial systems (see illustration in table 1).

The third test examines the associations of the *multiscale accessibility profiles* of settlements to their performance. The selected indicators classify settlement performance by size, functional and socio-economic characteristics. According to the governmental privacy policy (ICBS, 2008), data were available at different levels. We used data at the settlement level for *population* (n=953, included settlements comprising 98% of the population), *employees* (n=953, included settlements comprising 98% of the population), *commuters* (n=411, included settlements comprising 92% of the population) and *socio-economic index*[1] (n=194, included settlements comprising 90% of the population) (ICBS, 2008a,b,c).

3 Results

In order to examine the stability of accessibility levels across scales, our first test attempts to detect different spatial systems. Figure 1 presents the results of correlation matrix analysis between integration values across scales. This analysis highlights a clear trend of three distinct clusters corresponding to the three spatial accessibility systems: local,

[1] The *socio-economic index* is a combined measure of 16 indicators (3 demographic, 3 schooling and education, 5 employment and benefits and 5 standard of living). It should be note that those indicators not include data referring to size of population and employment that been used as addition indicators in our examination.

regional, and national (marked by green, blue and red, respectively). Indeed, high correlations are obtained within each cluster: at the local system ($r>0.90$), at the regional system ($r>0.85$) and within the national system ($r>0.80$) all of which are significant ($p<0.01$), while the relationships between the clusters were not statistically significant. This illustrates the main transition zones between the spatial systems at the intersections between the systems (marked by black circles), between 2 to 5 km from local to regional and between 15 to 30 km from regional to national. Overall, the results indicate three differentiated spatial accessibility systems.

Our second test explores the settlement's accessibility level, with distinction between high (H) and low (L) accessibility levels of each settlement in the three spatial accessibility systems exposed – local, regional and national - i.e. categorize settlement's multiscale accessibility profile (see section 2.3). The result (figure 2) reveals the spatial configuration of multiscale accessibility patterns: First, there are great differences between the HHH (red) clusters (metropolitans of Tel Aviv and Haifa) and LLL (blue) clusters (all small settlements in the periphery), namely, the settlements enjoying from high accessibility or suffer from low accessibility at all scales (respectively). Second, the green clusters are prominent in the peripheral region: the HHL (bright green) which represents the 'close periphery', including the secondary metropolitan areas of Jerusalem and Beer Sheva, while the HLL (dark green) include cities and the local councils in the 'far periphery'. Thus, in contrast to the HLL clusters, the HHL clusters contain significantly larger cities or municipalities close to dense urban areas. Third, the clusters of LLH (yellow), LHH (orange), and LHL (pink) are identified, mainly in the outer ring of the metropolitan of Tel Aviv. Those are small settlements enjoying high regional and/or national accessibility due to their relative closeness to dense urban areas but do not serve as functional centers, probably due to their low local accessibility. Fourth, the HLH cluster (brown) include medium to large cities with high local accessibility located in the national center but somewhat distant from the urban core region of the center.

The third test examines the associations between multiscale accessibility profile of settlement and their performance by size, functional and socio-economic characteristics (see section 2.3). The result (figure 3) shows complex associations between the categories of settlements that defined according to their multiscale accessibility profile to their performance. From functional perspective, most of the settlements with high local levels of accessibility (HHH, HHL, HLH and HLL) characterized by higher performance and intensified when cities are characterized also by high level accessibility at regional or national scale. In those clusters some small settlements are denoted with low performance. Those are small settlements neighboring dense urban areas received their high local accessibility level due to their proximity to urban area. In fact, those small settlements similar in their performance to other clusters (LHH, LHL, LLH and LLL), clusters of settlements having small size of population, employees and commuters related to low local accessibility. In contrast, from the socio-economic perspective it seems that national accessibility are much more important. Indeed, most cities with high levels of national accessibility (HHH, HLH, LHH and LLH) are characterized by higher socio-economic performance. This is further reinforced by the low socio-economic performance of the remaining clusters (HHL, LHL, HLL and LLL). It should be noted that for all indicators performance the differences between the highest (HHH) and lowest (LLL) clusters are the most significant, with a clear dominance of the HHH cluster over the rest of the clusters.

4 Conclusions

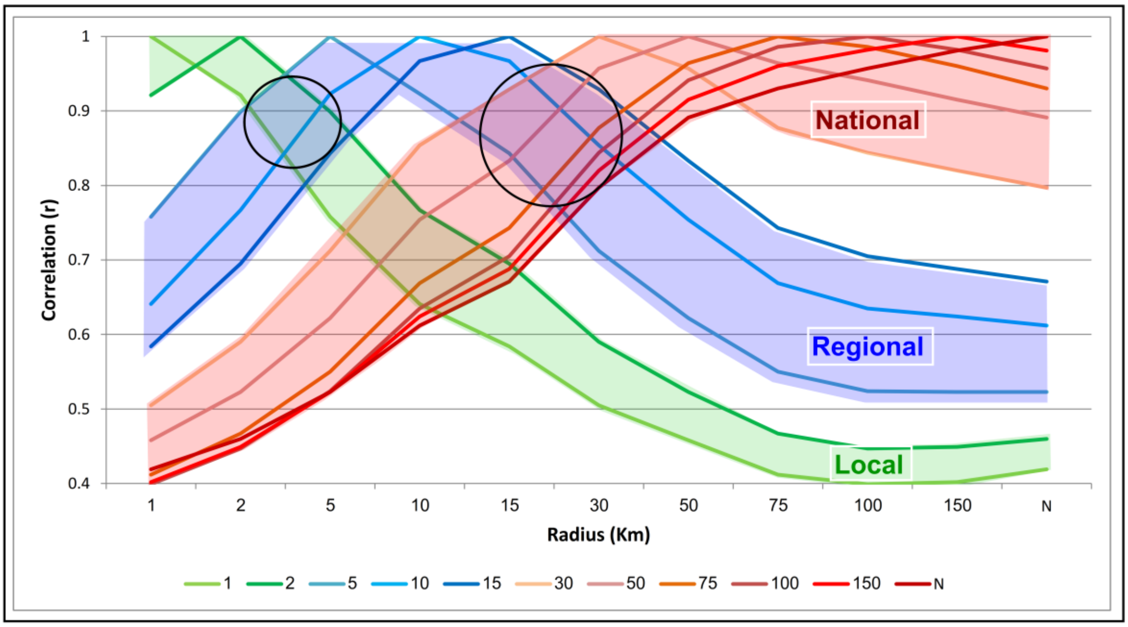
In this paper, we aimed to examine and to represent spatial multiscale accessibility of settlements across geographic scales, and to clarify its relationship to population size, functional and socio-economic characteristics. The multiscale accessibility examination of Israel road network exposes three differentiated spatial systems - local, regional and national. According to this, eight multiscale accessibility profiles at the settlement level were determined. We found that multiscale accessibility profiles of settlements strongly associate to settlements performance, while functional indicators associate to local accessibility and socio-economic indicators associate to national accessibility. The study findings indicate also that pervasive accessibility across spatial scales is integral part of settlements performance. Further research will try to detect settlement potential development according to their local-regional-national profile scores in the transition zones between the three spatial systems. Another research direction may include transforming of distance to travel-time terms in the analysis of multiscale accessibility.

Table 1: Illustration of settlements classification according to their multiscale accessibility profile - High/Low (H/L) level at local, regional and national spatial systems

Spatial system	Radius (Km)	HHH	LLL	HLL	HHL	HLH	LHH	LLH	LHL
Local	1km	H	L	H	H	H	L	L	L
	2km	H	L	H	H	H	L	L	L
Regional	5km	H	L	L	H	L	H	L	H
	10km	H	L	L	H	L	H	L	H
	15km	H	L	L	H	L	H	L	H
National	30km	H	L	L	L	H	H	H	L
	50km	H	L	L	L	H	H	H	L
	75km	H	L	L	L	H	H	H	L
	100km	H	L	L	L	H	H	H	L
	150km	H	L	L	L	H	H	H	L
	Nkm	H	L	L	L	H	H	H	L
Cluster	Local-Regional-National	High-High-High	Low-Low-Low	High-Low-Low	High-High-Low	High-Low-High	Low-High-High	Low-Low-High	Low-High-Low

Note: only full score of "High" (H) levels of accessibility at all spatial system radii gets a score of "High" (H) level of accessibility for this spatial system.

Figure 1: Pearson correlations between the Integration values of settlements across spatial scales (Km).



Note: Clustering of local (*green*), regional (*blue*) and national (*red*) radii according to the correlation between integration values of settlements. The black circles remark the transition zones between the spatial systems. All correlations are significant (p<0.01).

Figure 2: Spatial pattern of multiscale accessibility at the settlement level

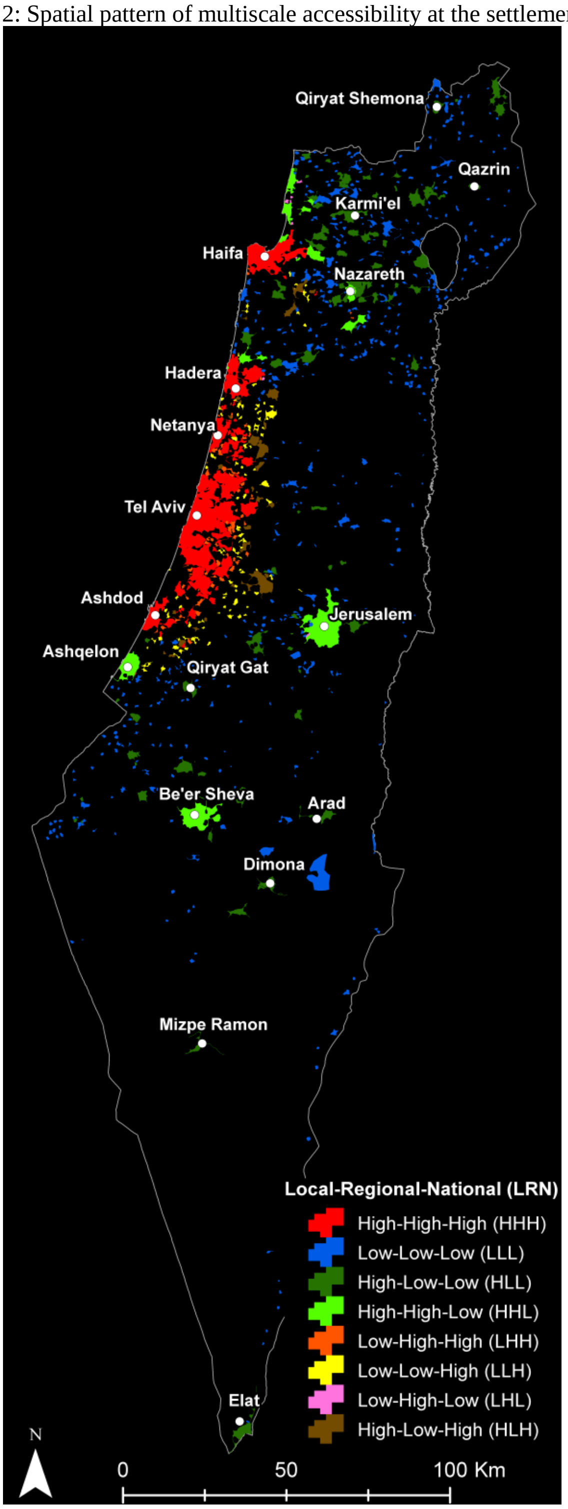
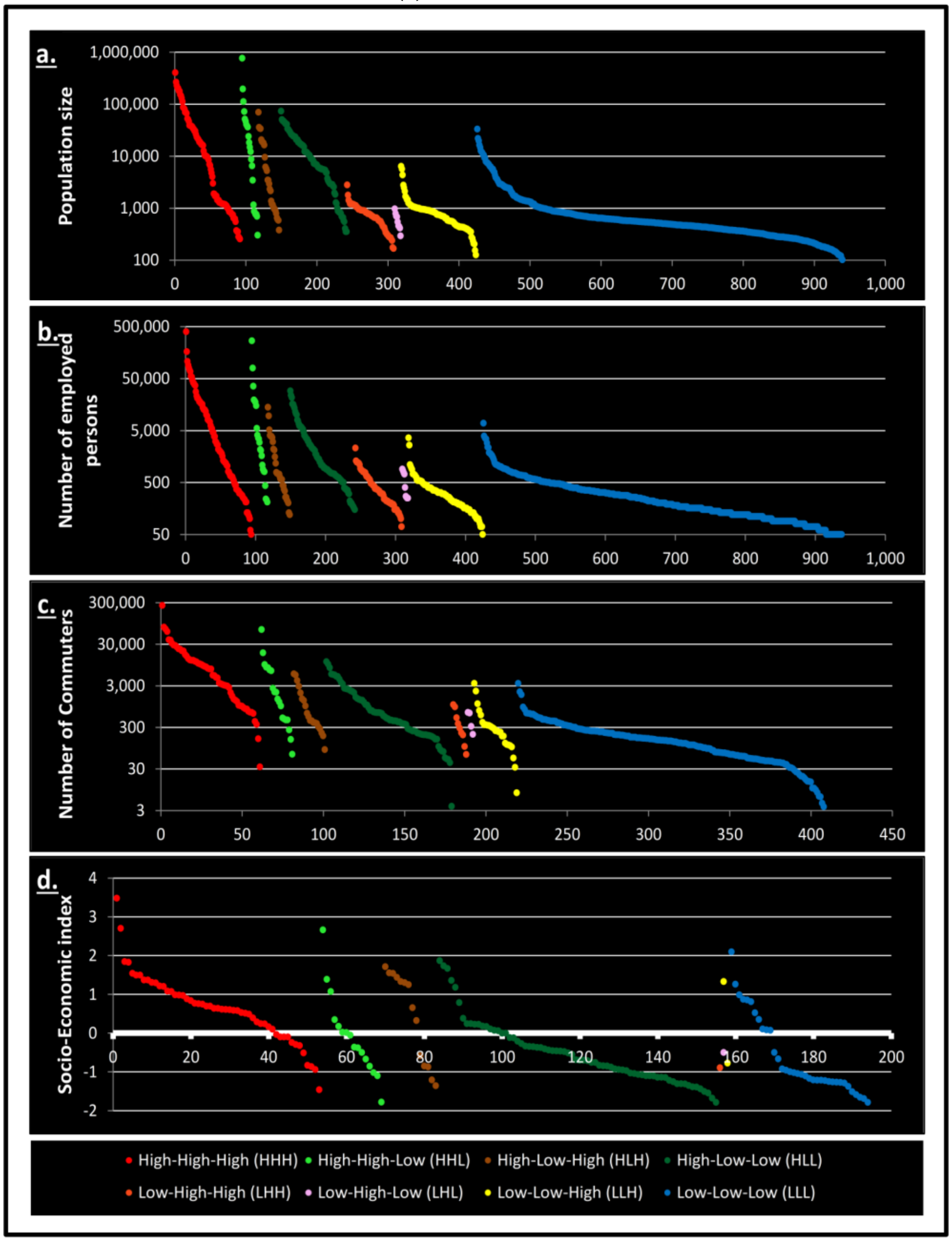


Figure 3: The associations between settlement profiles and performance: (a) population size (b) employed (c) commuters (d) Socio-Economic index.



5 References

Al Sayed, K., Turner, A., Hillier, B., Iida, S., et al. (2014) *Space Syntax Methodology*. 4th edition. Bartlett School of Architecture, UCL, London.

Batty, M. (2009) Accessibility: In Search of a Unified Theory. *Environment and Planning B: Planning and Design*. [Online] 36 (2), 191–194..

Benenson, I., Martens, K., Rofé, Y. & Kwartler, A. (2011) Public transport versus private car GIS-based estimation of accessibility applied to the Tel Aviv metropolitan area. *The Annals of Regional Science*. [Online] 47 (3), 499–515.

Geurs, K.T. & van Wee, B. (2004) Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*. [Online] 12 (2), 127–140.

Hillier, B. (2009) Spatial Sustainability in Cities: Organic Patterns and Sustainable Forms. *roceedings of the 7th International Space Syntax Symposium*. K01:20.

Hillier, B., Yang, T. & Turner, A. (2012) Normalising least angle choice in Depthmap: and how it opens up new perspectives on the global and local analysis of city space. *The Journal of Space Syntax*. 3 (2), 155–193.

ICBS- Israel Central Bureau of Statistics (2008a). *Table 4.24- Employees population aged 15 and over, by locality of residence and by employment centres.*

ICBS- Israel Central Bureau of Statistics (2008b). *Employees in localities and statistical areas* (unpublished, Hebrew).

ICBS- Israel Central Bureau of Statistics (2008c). *Physical data - municipalities and local councils* (Hebrew).

ICBS- - Israel Central Bureau of Statistics (2018). *Statistical Abstract of Israel 2018.*

Jiang, B. (2013) Head/Tail Breaks: A New Classification Scheme for Data with a Heavy-Tailed Distribution. *The Professional Geographer*. [Online] 65 (3), 482–494.

Krenz, K. (2017) Employing Volunteered Geographic Information In Space Syntax Analysis. *Proceedings of the 11th Space Syntax Symposium*. 150:1-26.

Law, S. & Versluis, L. (2015) How do UK regional commuting flows relate to spatial configuration? *Proceedings of the 10th International Space Syntax Symposium*. 74:1-21.

Omer, I. & Jiang, B. (2015) Can cognitive inferences be made from aggregate traffic flow data? *Computers, Environment and Urban Systems*. [Online] 54, 219–229.

Omer, I. & Kaplan, N. (2018) Structural properties of the angular and metric street network's centralities and their implications for movement flows. *Environment and Planning B: Urban Analytics and City Science*. [Online] 0 (0), 1–19.

Parham, E., Law, P. of the 11th S.S.S. & Versluis, L. (2017) National Scale Modelling To Test UK Population Growth And Infrastructure Scenarios. *Proceedings of the 11th Space Syntax Symposium*. 103:1-17.

Serra, M., Hillier, B. & Karimi, K. (2015) Exploring countrywide spatial systems: Spatio-structural correlates at the regional and national scales. *Proceedings of the 10th International Space Syntax Symposium*. 84:1-18.

Serra, M. & Pinho, P. (2013) Tackling the structure of very large spatial systems - Space syntax and the analysis of metropolitan form. *The Journal of Space Syntax*. 4 (2), 178–196.

Susilo, B. (2017) Multiscale Spatial Assessment of Determinant Factors of Land Use Change: Study at Urban Area of Yogyakarta. *IOP Conference Series: Earth and Environmental Science*. [Online] 98, 012015.

Wachs, M. & Kumagai, T.G. (1973) Physical accessibility as a social indicator. *Socio-Economic Planning Sciences*. [Online] 7 (5), 437–456.