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The spatial organization of accessibility and functional hierarchy: The case of Israel

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ABSTRACT

Accessibility is a well-known basic term in spatial science and planning and is inherently related to functional aspects of places and regions. Although previous studies have examined functional systems and spatial accessibility few have attended to the association among them across geographical scales. Our study attempts to fill this gap. 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 analysis was based on angular segment analyses of the road center-line network. Following this, the correlation between spatial accessibility across scales and functional performance of employment and commuting flows was examined.

The study findings show a significant correspondence and exposes transitions between local, regional and national spatio-functional systems. First, a significant correlation between local (2 km radius) accessibility levels of settlements with the number of employees and commuters. Second, the regional/metropolitan system (10–15 km radius) accessibility is highly correlated to the emergence of the main employment centers. Third, the main metropolitan areas are integrated at higher scale (from 30 km radius) and form together a core region characterized by high accessibility as well as well connectivity through commuting flows. In contrast, no substantial commuting flows were found within the periphery, as well as between periphery-core. The findings show clearly that this functional structure corresponds to the multi-scale accessibility levels of settlements. We conclude that the core region functions at multiple scales (local-regional-national) while the periphery functions mostly at a local scale.

1. Introduction

Accessibility is a well-known basic term in physical and urban planning and many definitions have been proposed (Chen & Yeh, 2019; Geurs & van Wee, 2004; Handy & Niemeier, 1997; Hansen, 1959; Markovich, 2013). A simple definition 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 has enormous association to its functional, economic and social aspects (Erkut & Özgen, 2003; Geurs & van Wee, 2004; Spiekermann & Neubauer, 2002) with significant potential effects on future potential development (Hansen, 1959; Wachs & Kumagai, 1973).

Road networks are the basic elements that allow accessibility connecting places from the small scale (neighborhood/settlement) through the medium (cities) to the regional and national scales (Parham, Law, & Versluis, 2017; Serra & Pinho, 2013). Previous studies have analyzed accessibility in specific contexts or for a specific area, usually only up to the city or metropolitan level (e.g., Benenson, Martens, Rofé, & Kwartler, 2011; Curtis, 2011; Hansen, 1959) without explicit reference to the larger context as part of the national system. However, cities are indeed an integral and critical part of regional and national contexts which greatly affect their functional potential (Law & Versluis, 2015; Serra, Hillier, & Karimi, 2015). For example, it has been found that even metropolitan regions are unsuitable for functional analysis due to the strong linkages with their surrounding environs (Bar-El & Parr, 2003a; Pain, 2008).

Accessibility analysis at regional or country scales is not new, returning to the classical *locational theories* from the mid-19th century which incorporated the spatial dimension into economic models by

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examining existing settlement patterns according to economic and physical considerations. These theories emphasized that location and size of settlements in a given space is significantly affected by proximity to other places by geographic location, distance and size of the neighboring populated centers (Portugali, 2011, p. 17–37), specifically, a city's relative accessibility. However, these earlier studies suffered from coarse definitions due to their limited information and lack of knowledge, technologies, computing power and data resolution. Currently, the advantages of state-of-the-art geographic information (GI) technologies allow the rapid analysis of accessibility at a national context with greater resolution and finer granularity.

Indeed, several recent studies have investigated accessibility at an unprecedented national scale, based on road network analysis, up to the street segment level (Law & Versluis, 2015; Parham et al., 2017; Serra et al., 2015). However, these studies were conducted only in the United Kingdom and without explicit reference to the transitions among different functional systems across multiple scales. These studies also have given little attention for the national space context.

It has been suggested that economic activities organize and divide the national space into core (center) and peripheral regions according to the *agglomeration principle (*Weber, 1929*, p. 124–172)*. Briefly, increasing returns and scale-of-economies are stronger when transportation costs are low and, therefore, it is expected that a concentration of economic activity in a core region will lead to concentration of population around this area. Consequently, the rest of the space (periphery) is less dense and more diffuse with concomitantly lower economic activity. This process is expected to continue through a circular causality of positive feedback leading to *core-periphery* structure (Krugman, 1991, 1999). In general, it can be argued that this creates a simple spatial division between center and periphery with the center characterized by high accessibility to activities (such as work, shopping or leisure) and opportunities (such as markets or jobs) and the periphery region being characterized by low accessibility to those features (Schürmann & Talaat, 2000; Spiekermann & Neubauer, 2002).

However, this simple dichotomy between core-periphery is unsuitable for all countries (e.g., Bar-El & Parr, 2003b) and distinctions between center and periphery may be more complex. For example, there may be multiple concentrations of economic activity in more than one region (Krugman, 1999) with other attractors distributed in space (e.g., education, health and commercial services). These then produce changes in the spatial population distributions, thereby leading to feedback circular causation processes (Bar-El & Parr, 2003b). Also, policy interventions at multiple levels of governance may modify structural conditions at a national level. Differential taxes or rapid transit infrastructure may, for instance, significantly reduce the locational disadvantages of peripheral regions (Copus, 2001; Lanaspa, Pueyo, & Sanz, 2001). These aspects are reinforced by findings indicating that the center-periphery structure can be envisioned from a monocentric into a polycentric structure (Copus, 2001). This is similar to the phenomenon observed in urban-metropolitan regions (Hall & Pain, 2006; Pain, 2008; Zhong et al., 2017). Noteworthy is the possibility of intermediate structures between them (Burger & Meijers, 2012; De Goei, Burger, Van Oort, & Kitson, 2010). Accordingly, it may be assumed in this paper that a comprehensive national scale analysis should be conducted from a multi-scale level perspective, from the small scale to larger ones, in order to characterize the emergence of different spatio-functional systems.

To implement our suggested approach, we assume that network analysis methodologies can be suitable for high-resolution spatial configuration analyses. These methods focus on the relative centralities of each road segment and the correlation to different socio-economic and functional indicators. Indeed, network centralities have been found to be significantly correlated with a variety of functional phenomena at the urban and regional scale level, such as movement distribution (Omer, Rofè, & Lerman, 2015; Penn, Hillier, Banister, & Xu, 1998), land use patterns (Ozbil, Peponis, & Stone, 2011; Scoppa & Peponis, 2015), liveliness and regeneration of urban environment (Ortiz-Chao & Hillier, 2007; Vaughan, Jones, Griffiths, & Haklay, 2010). They have also been shown to be a powerful tool for transportation and urban planning (Karimi, 2012; Lerman, Rofè, & Omer, 2014), including assessment of planning interventions at the urban scale (Cooper, Harvey, Orford, & Chiaradia, 2018; Marcus, Ståhle, & Dahlhielm, 2010; Raford & Ragland, 2006). Usually, at the national scale, most studies focus on modeling vehicular movement with little attention to the functional context (Jiang, Zhao, & Yin, 2008; Serra & Hillier, 2018).

Recently, several studies have demonstrated the associations of the national spatial configuration with several types of functional and socio-economic aspects (Serra et al., 2015), commuting patterns (Law & Versluis, 2015) and the growth potential of cities (Parham et al., 2017). These studies were based on the Space Syntax methodological framework, a set of theories and techniques for topo-geometric analysis of spatial configurations across various geographical scales (Al Sayed, Turner, Hillier, Iida, & Penn, 2014). Based on centrality analysis of the road network, a complex relationship was exposed between the spatial structures to functional and social-economic indicators across different spatial scales. For example, spatial accessibility, based on measures of integration, was found to be highly correlated with population density ($R^2 = 0.83$ at radius of 5 km), workplace density ($R^2 = 0.81$ at radius of 5 km), the number of commuters ($R^2 = 0.51$ at radius of 10 km) (Law & Versluis, 2015), working population density ($R^2 = 0.56$ at radius of 2 km) and movement volume ($R^2 = 0.47$–0.68 in radius of 10–20 km) (Serra et al., 2015). However, little attention was given to the spatio-functional hierarchy resulting from the structural relationships between spatial accessibility and functional distribution at different scales. A first step in this direction, though limited to a regional level, has shown that the spatial patterns of accessibility of the Oporto metropolitan region, Portugal, are linked to the general spatial division of neighborhood, city and region (Serra & Pinho, 2013).

Another proposition that may be termed as a functional approach, argues that different functional aspects operate over multiple scales and levels (Burger, van der Knaap, & Wall, 2014; Pain, 2008) and that the functional linkage between functional areas is mainly determined by flows of people between regions and not determined merely by a physical connection (Burger & Meijers, 2012; Hall, 2009; Razin & Charney, 2015). Indeed, a high correlation was found between accessibility of an area and the number of commuters (Law & Versluis, 2015). Even so, these kind of analyses were conducted mainly at urban (Roth, Kang, Batty, & Barthélemy, 2011; Zhong et al., 2016) and regional scales (Adrienko & Adrienko, 2011; Burger et al., 2014). National scale analyses are usually limited to coarse regional divisions (e.g., Givoni, 2017). Furthermore, the reliance on "commuting sheds" or population flows to define functional area boundaries may lead to substantially diff ;erent regional boundaries (Schleith, Widener, Kim, & Liu, 2018). Therefore, the analysis of functional structures with respect to the accessibility-based spatial configuration is actually combines between both approaches. In that paper we refer to multi-scale accessibility, where the regional or country scales play important role.

As described above, intensive work has been done on spatial systems and on functional systems; nevertheless, an integrative spatio-functional approach is lacking and has not been examined in detail, especially at the national scale. This study attempts to fill this gap. Based on the assumption that *"accessibility is perhaps the most important concept in defining and explaining regional form and function"* (Wachs & Kumagai, 1973), this study analyzes multi-scale spatial accessibility in order to capture the emergence of distinct spatial accessibility systems and their relation to the formation of particular functional systems, from local levels up to the national scale. The multi-scale approach suggested here is consistent with the necessity to explicitly associate functional activity with the physical infrastructure while emphasizing the relevance of spatial scales for analysis (Batty, 2009).

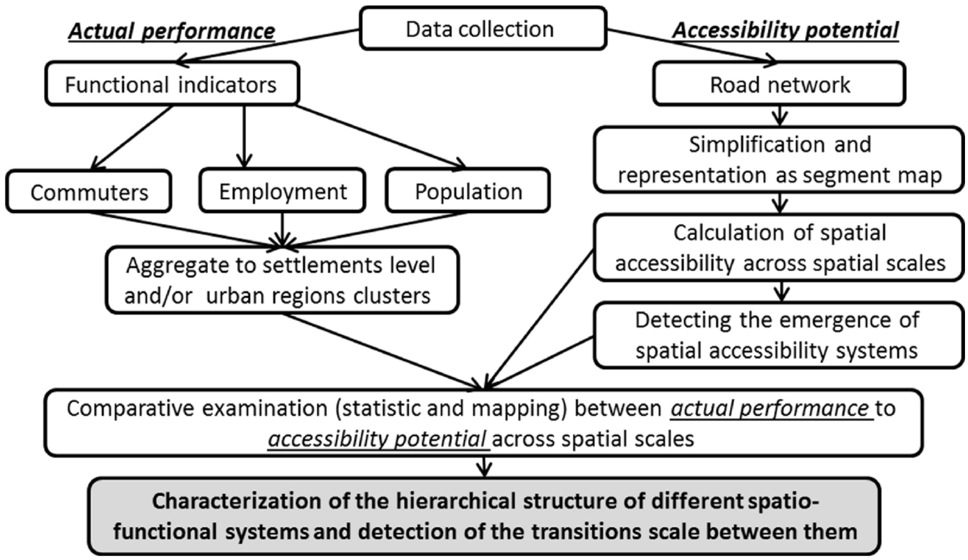

Fig. 1. Methodological framework.

2. Methodological framework

A spatio-functional national analysis should consider four main aspects. First, characterization of the hierarchical structure of different spatial accessibility systems. Second, identification of functional structures. Third, an examination of the associations between spatial to functional systems across scales. Fourth, detection of the transitions between the different functional systems based on different spatial scales. Therefore, the methodological framework implemented in this paper includes data collection and analysis in two directions. The first aimed to expose accessibility potential at different scale, while the second aimed to reveal functional divisions (Fig. 1). Then, comparative examinations were performed in order to characterize the hierarchical structure of different spatio-functional systems and detect the transitions of scale between those systems.

2.1. Case study

Israel is a small country (size of 22,072 km^2; approximately 9 million citizens), densely populated (387/km^2 in all land area and 7,117/km^2 in the built area) with a developed economy. It is characterized by high urbanization levels with a rapid history of development (ICBS-Israel Central Bureau of Statistics, 2018). Policies of population dispersal have been implemented throughout the 20th century, beginning with geopolitical considerations and later for reducing the evolutionary processes of *gravity cities* (Portugali, 2011, p. 32–34), *agglomeration* (Weber, 1929, p. 124–172) and the *core-periphery* (Krugman, 1991, 1999) organization of space. Those interventions have largely been ineffective, especially, in relation to the inequalities observed between center and periphery (Asif, Golan, Porat, & Polinov, 2014; Bystrov, 2008). The concentration in the core region, increased by the sprawl processes three decades ago (Frenkel & Ashkenazi, 2008) has led to support the spatial development of four metropolitan centers: Tel Aviv, Haifa, Jerusalem and Be'er Sheva (Asif et al., 2014). Yet, the dominance of the Tel Aviv metropolitan gradually percolated outward to overshadow all other metropolitan areas. Ideas of improving transportation infrastructure to allow functional integration of peripheral regions to the metropolitan labor market have not yet been achieved (Razin & Charney, 2015). Investments in long-distance transport infrastructure in Israel have been found to actually increase the dependency of the periphery on the center while increasing core-periphery disparities (Givoni, 2017; Rotem-Mindali & Geffen, 2014).

Center-periphery relations in Israel are strongly associated with socio-economic gaps and lack of opportunities in the periphery versus the center (e.g., Bystrov, 2008; Shokeid, 2011). Other essential questions in this context concern the center's *carrying capacity* (transport, land use, garbage, sewage etc.) due to the accelerated development, especially in the Tel Aviv region (Bystrov, 2008; Soffer & Bystrov, 2006). These fundamental issues are primarily related to strategic spatial planning initiatives (Asif et al., 2014). The national perspective, along with attention to regional divisions (Bar-El & Parr, 2003b) and the necessity to engage local development of the periphery (Bystrov, 2008; Rotem-Mindali & Geffen, 2014) require a multi-scale view of the national space in a manner that has not yet been examined in Israel. A nationwide spatio-functional examination is a vital step towards long-term strategic planning efforts for Israel.

This study proposes to examine the relationships of spatial structure (Section 2.2) and functional structure (Section 2.3) in Israel, giving a countrywide spatio-functional perspective. The investigation was based on 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 on population, employees and commuters (ICBS- Israel Central Bureau of Statistics, 2008a, 2008b, 2008c, 2008d, 2008e, 2008f, 2008g, 2008h).

2.2. National road network model

Mobility modes to work in Israel, including mode split of journeys, are clearly based on usage of the road networks: ~57 % by private car, ~18 % by public bus, ~11 % by foot, ~9 % by workplace transportation, 0.6 % by train, and 4 % by other modes) ICBS- Israel Central Bureau of Statistics, 2008c). These figures reinforce the necessity of road network accessibility for the Israel national scale analysis.

The road network in Israel is disconnected, a kind of “island state”, without continuity to surrounding countries. The national road network model used in this study is based on data for the entire Israel paved road system (Fig. 2a). The original road representation is skeletal and it was transformed into Road Center-Lines (RCL) based on different road types. Subsequently, their geometries were simplified in order to reduce unnecessary complexity, as suggested by Krenz (2017a) and as performed in similar ways previously (Parham et al., 2017; Serra & Hillier, 2018). This process transforms the road network into road segment map which was found to be consistent with the results of the “traditional” Space Syntax segment line model (Krenz, 2017a). The final national road network model includes 333,303 nodes (road segments). These

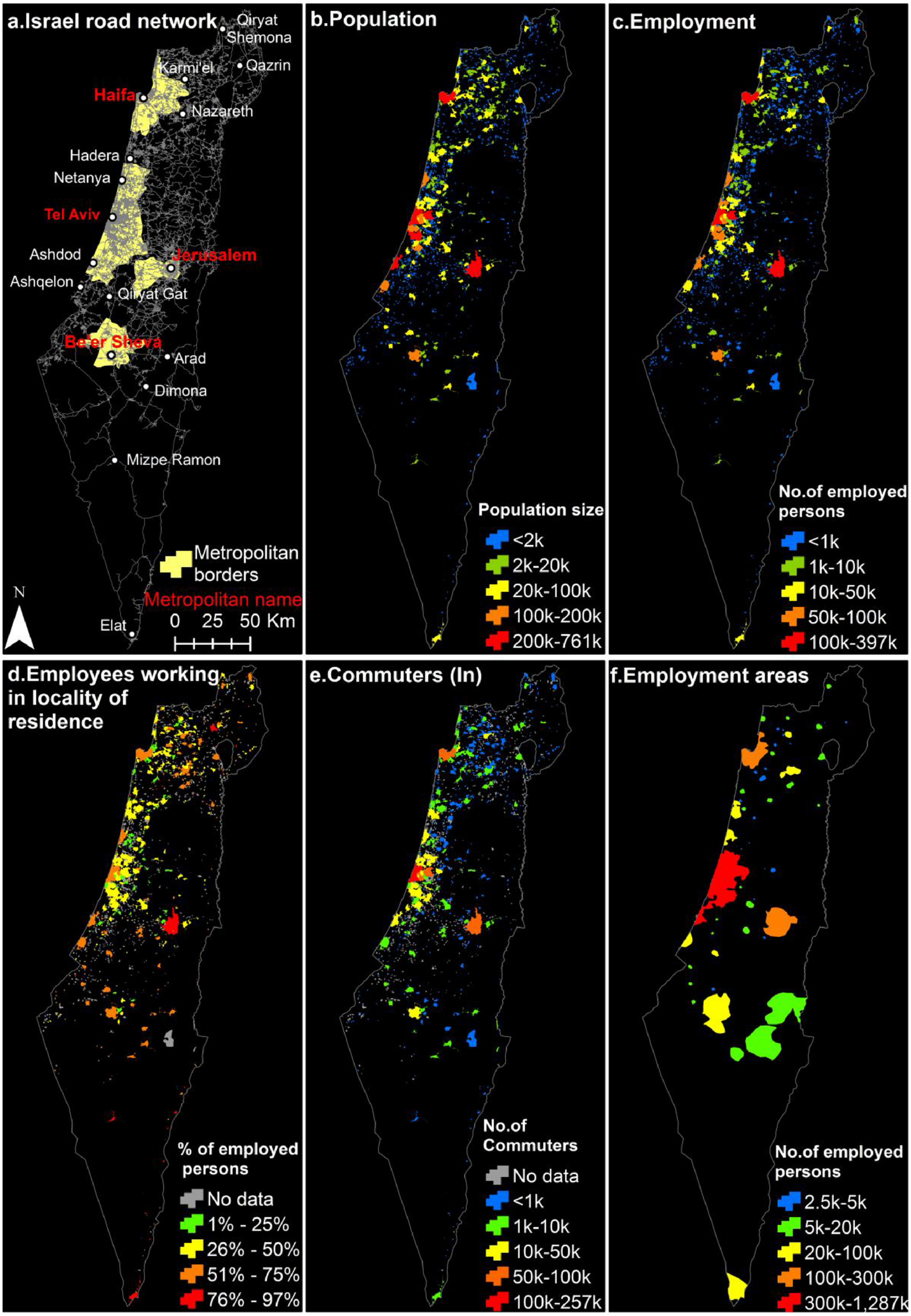

Fig. 2. Israel case study. a. Israel road network; b. population at the settlement level; c. employees at the settlement level; d. employees (%) working in locality of residence; e. commuters (in) at the settlement level; f. employment areas with more than 2500 employees. The 11 main employment centers (> 20k employees) are marked by yellow, orange and red colors according to their size. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

steps of processing were done in ArcGIS (ver. 10.3).

Further, the spatial configuration of Israel's road network was analyzed based on angular segment analysis (i.e., 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 & Pinho, 2013; Serra et al., 2015). In order to examine the spatial accessibility in Israel, we adopted the centrality measure of *Integration* which corresponds to the graph-based *Closeness* centrality measure (Hillier & Iida, 2005). This measure describes how close a given node (road segment) is to all other nodes and represents the degree of accessibility for each road segment in the network at the entire road network (radius *N*) (Jiang, 2009; Omer & Jiang, 2015). Formally, the closeness measure is defined by:

$$Closeness(V_i) = \frac{n-1}{\sum_{k=1}^{n} d(V_i, V_k)}$$

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 (V_i) to every other road segments (node V_k) in the segment map.

In order to reveal the emergence of different spatial systems and to cover all relevant scales for the national spatial analysis, integration measures were calculated for a large set of radii representing different spatial scales. The chosen radii were selected as follows. First, measurements were conducted with similar radii used in relevant accessibility studies that have been conducted at the national scale (e.g., Law & Versluis, 2015; Serra et al., 2015). Second, in cases of low correspondence between the integration values in adjacent radii, we added additional radii according to the principle that the integration value for each radius strongly correlates to the integration value in the adjacent radius ($r > 0.9$). Accordingly, it can be assumed that there are no hidden scales between the chosen radii. The final chosen radii are: 0.5, 1, 1.5, 2, 3, 4, 5, 7.5, 10, 12.5, 15, 20, 25, 30, 40, 50, 75, 100 and 150 km. It is also important to note that closeness represents the *to-movement* potential, i.e., the potential of a given location to be a destination or origin for movement within the network for defined radius (Hillier & Iida, 2005). Therefore, it is suitable for examining differences between aggregated movement (journeys to work) and movement potential over different spatial scales. The calculation of integration centralities was performed using the Depthmap software (ver. 10.3, UCL).

2.3. Functional indicators

In order to examine the functional aspect in Israel several variables of the labor market were used. The first data source (ICBS- Israel Central Bureau of Statistics, 2008d) includes data for 2,800,440 employees and their workplace location at the settlement level (Fig. 2c), referring to employees having a permanent and known workplace. Data for 185,110 employees with unknown workplace and those without a permanent workplace (45,320, 139,790, respectively) are not included here. These datasets are limited due to privacy policies imposed by law (ICBS- Israel Central Bureau of Statistics, 2008a, 2008b, 2008c, 2008d, 2008e, 2008f, 2008g); for example, data is unavailable for small settlements with less than 30 employees, thereby reducing the number of settlements in the study from 1218 to 953. The population distribution for these settlements, which accounts for 98 % of population, can be classified according to the ICBS into *rural settlements* (< 2k residents, n = 733), *urban settlements* (2k-20k residents, n = 145), *small cities* (20k-100k residents, n = 61), *medium cities* (100k-200k residents, n = 8), and *major cities* (> 200k residents, n = 6) (Fig. 2b).

The second dataset (ICBS- Israel Central Bureau of Statistics, 2008a, 2008d) includes data on the number of commuters at the settlement level (Fig. 2e). This variable was calculated from the total number of employees in the locality (Fig. 2c) while subtracting the number of employees with residence in the locality (Fig. 2d). The data includes only records and information on 411 settlements, due to the aforementioned privacy policy. For a detailed and expanded examination we used data of commuting flows to 93 main cities (ICBS- Israel Central Bureau of Statistics, 2008f) (Fig. 6a, b) comprising 80 % of the population.

The third dataset aimed to construct employment areas independent of municipal boundaries. The ICBS- Israel Central Bureau of Statistics (2008a) has implemented an Inverse Distance Weighted (IDW) model for spatial interpolation of the distribution of employees in localities. Regions with more than 2500 employees were then aggregated into employment regions (Fig. 2f). This resulted in 53 employment areas containing 87 % of the total employees. Among them, 11 main employment centers were selected by the researchers according to their size. To develop a more "natural" definition for the 11 main employment centers, the data was reanalyzed by adopting a cutoff of > 20k employees which resulted in 11 areas with 77 % from the total employees in Israel. These main areas differ from the original analysis conducted by the ICBS- Israel Central Bureau of Statistics (2008a) that refer to areas size and we chose to refer to the employment size, i.e. the 11 largest employment centers. Following this, we used commuting flow patterns to the main employment centers obtained from the ICBS- Israel Central Bureau of Statistics (2008a) for a comprehensive examination (Fig. 6c). Unfortunately, this data is limited to commuting among main employment centers or from large settlements to the main employment centers (constitute 95 % of the commuters to the main employment centers), due to the privacy policy. It should be noted that data of commuting flows (ICBS- Israel Central Bureau of Statistics, 2008a, 2008f) reflect the main commuting patterns, promoting the assumption that there are no other significant commuting patterns in Israel.

2.4. Statistical methods

In order to reveal distinct spatial accessibility systems we implemented Principal Components Analysis (PCA) and Principal Axis Factoring (PAF). Both methods have been used in regional studies. PCA was used by Serra and Pinho (2013) for identifying significant variability trends in the spatial distribution of centrality values, while the PAF was used by Krenz (2017b) to extract latent centrality structures reflected by centrality patterns at diff ;erent radii. Briefly, performing PCA over all integration values across all scales reduce the number of original variables (spatial scales) to a minimum number of components when the their number determined by the eigenvalue criterion (Serra & Pinho, 2013). In contrast, PAF produces common factors of measured variables, those common factors which are unobservable latent constructs that conjecturally cause the measured variables. PAF is capable of partitioning the variance of measured variables into common variance and unique variance, in contrast to the components of the PCA derived directly from measured variables (Krenz, 2017b). Both methods provide factor scores aimed to assist in the identification of natural scales for the distinct spatial accessibility systems. These analyses were done using SPSS (ver. 22, IBM).

In order to reveal the relation of different spatial accessibility systems with the formation of different functional systems, we regressed the data of road network accessibility to the functional divisions. Similar to other studies (Law & Versluis, 2015; Serra et al., 2015), the average *Integration* value for each settlement and for each employment area (Fig. 2c, f) was calculated by taking the mean *Integration* value of all road segments within each polygon for the settlement or employment area, respectively. Mean integration was calculated for all spatial radii chosen (see Section 2.2 above). Because the functional indicators and the spatial accessibility of settlements and employment areas are characterized by long-tail distributions, the variables were log-transformed to stabilize the variance. This allows the use of Pearson correlation and linear regression to examine the associations between several functional indicators to accessibility level at different spatial scales.

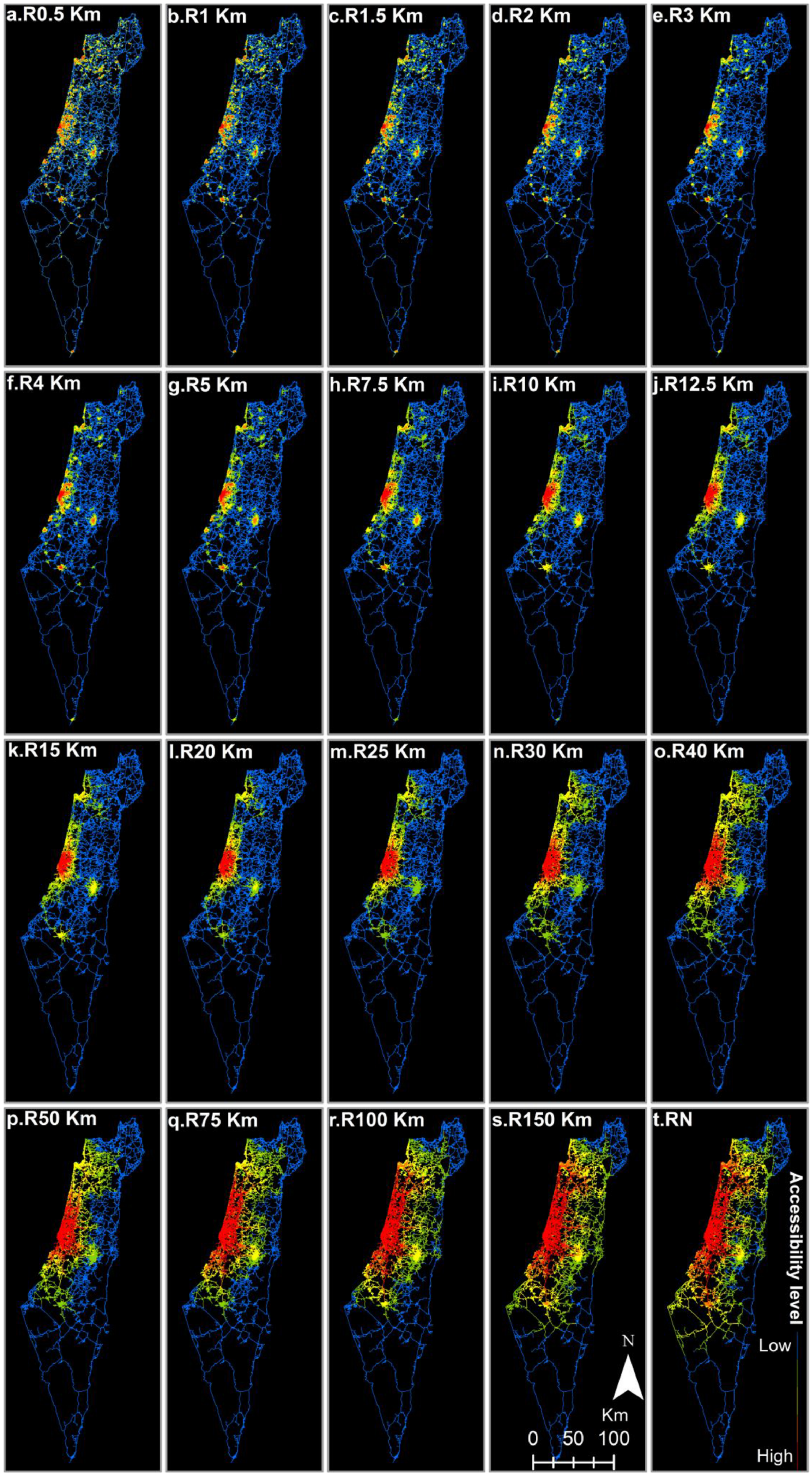

Fig. 3. Accessibility level (Integration centrality) at Radius of: a. 0.5 Km; b. 1 Km; c. 1.5 Km; d. 2 Km; e. 3 Km; f. 4 km; g. 5 Km; h. 7.5 Km; i. 10 Km; j. 12.5 Km; k. 15 Km; l. 20 Km; m. 25 Km; n. 30 Km; o. 40 Km; p. 50 Km; q. 75 Km; r. 100 Km; s. 150 Km; t. N (global accessibility).

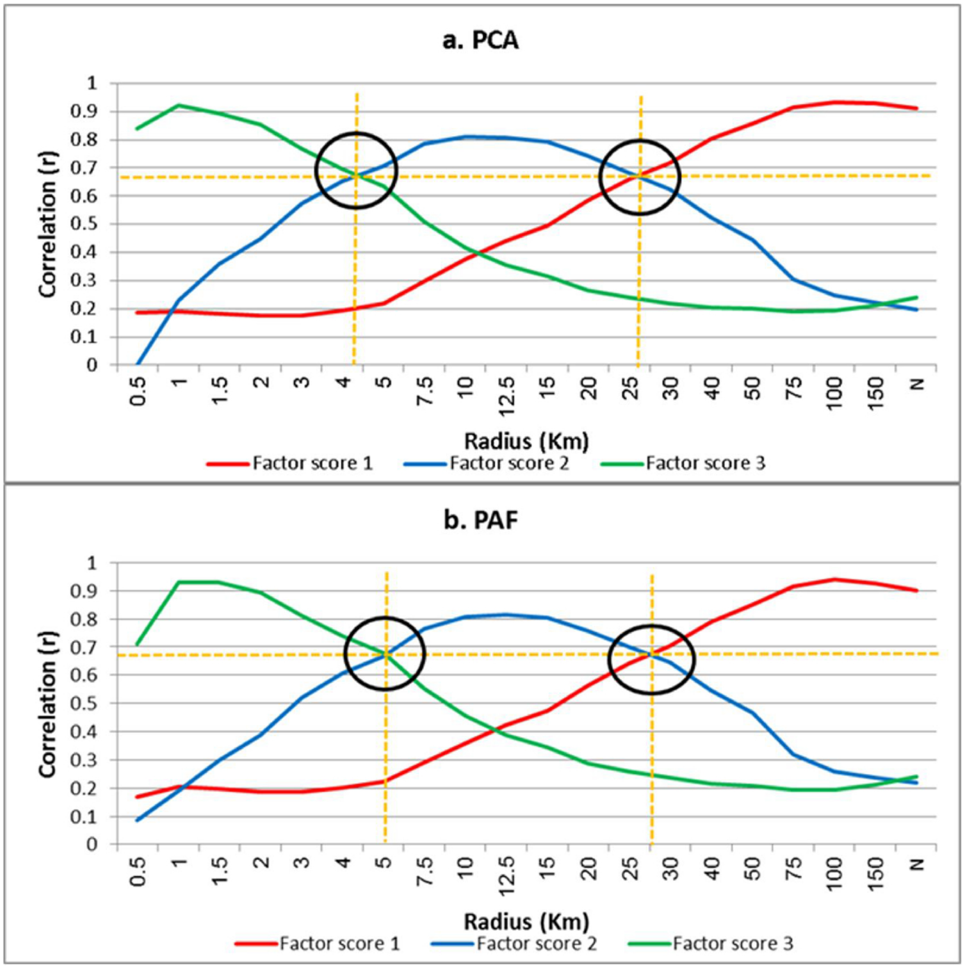

Fig. 4. Correlations between segments factor scores to Integration values across spatial scales (Km), when: (a) the factor scores are based on PCA; (b) the factor scores are based on PAF; the black circles remark the transition zones between the spatial systems. All correlations are significant ($p < 0.01$); the three PCA and the PAF factors may able to explain 95 % and 95 % of the original variables, respectively.

3. Results

3.1. The emergence of spatial accessibility systems

The Integration centrality measure exposes twenty patterns of accessibility levels across various spatial scales (Fig. 3). This allows a high resolution examination of the spatial configuration of Israel. In general, the formation of several spatial systems is indicated with the increase of scale to the national scale (radius *N*). At lower scales, a patchy structure of high accessibility is exhibited and this corresponds very well to the municipality boundaries of urban settlements (see also Fig. 2b). As the scale increases, by increasing the radius of the analysis, some “hotspots” disappear while others remain distinct and conforming to the municipal boundaries of medium and large cities smaller communities in denser areas begin to merge into larger clusters of urban regions. Ultimately, the four metropolitan areas in Israel are revealed by this methodology (Fig. 1a). At larger scales integration between the main metropolitan areas forms a core region (center) with a clear distinction from the unintegrated region (periphery) according to accessibility levels.

More explicitly, three main spatial accessibility systems are identified: the *local*, the *regional* and the *national scales*. The *local* spatial system appears in the radius of 0.5–4 km (Fig. 3a–f) and emphasizes in the medium level of accessibility most of the urban settlement in Israel while in the higher level of accessibility highlights the cities (see also Fig. 2b). Conversely, the rural settlements are not sufficiently connected in order to create a high accessibility potential which means there is an inability to generate significant to-movement potential (potential to be a destination). The *regional* spatial system appears from 5 km up to 20–25 km (Fig. 3g–m) and is characterized by clusters of highly accessible urban regions in dense areas (especially, in the central and coastal Tel Aviv area) while medium cities with medium levels of accessibility are highlighted in isolated regions. From the range of 10 km (Fig. 3i) there is a tendency to formation the four metropolitan areas (see also Fig. 2a) which are prominent from medium accessibility levels within the radius of 15 km. The next spatial system, the *national*, begins to form by integration of the inter-metropolitan space, through to the 30 km radius (Fig. 3n), and continues to merge into one apparent core region (center). At the larger radius of analysis (> 75 km, Fig. 3q–t) the national core-periphery structure is clearly distinguishable by accessibility levels: high accessibility level of the core region (center), low accessibility level of the periphery region, and some buffer zone between them characterized by medium accessibility level..

The detection of the three spatial accessibility systems is supported by the results obtained from the PCA and PAF analyses. The correlation between the segments factor scores of PCA and PAF vs. integration values across scales are plotted in Fig. 4a and b, respectively. Strong robustness is observed for the spatial systems where both methods provide comparable results. Clear trends of three distinct spatial accessibility systems are exhibited - local, regional, and national (marked by green, blue and red, respectively). Factors 1, marked by red lines, highly correlate ($r > 0.70$) to the national scales (30 Km to radius N), factors 2, the blue lines, highly correlate ($r > 0.66$) to the regional

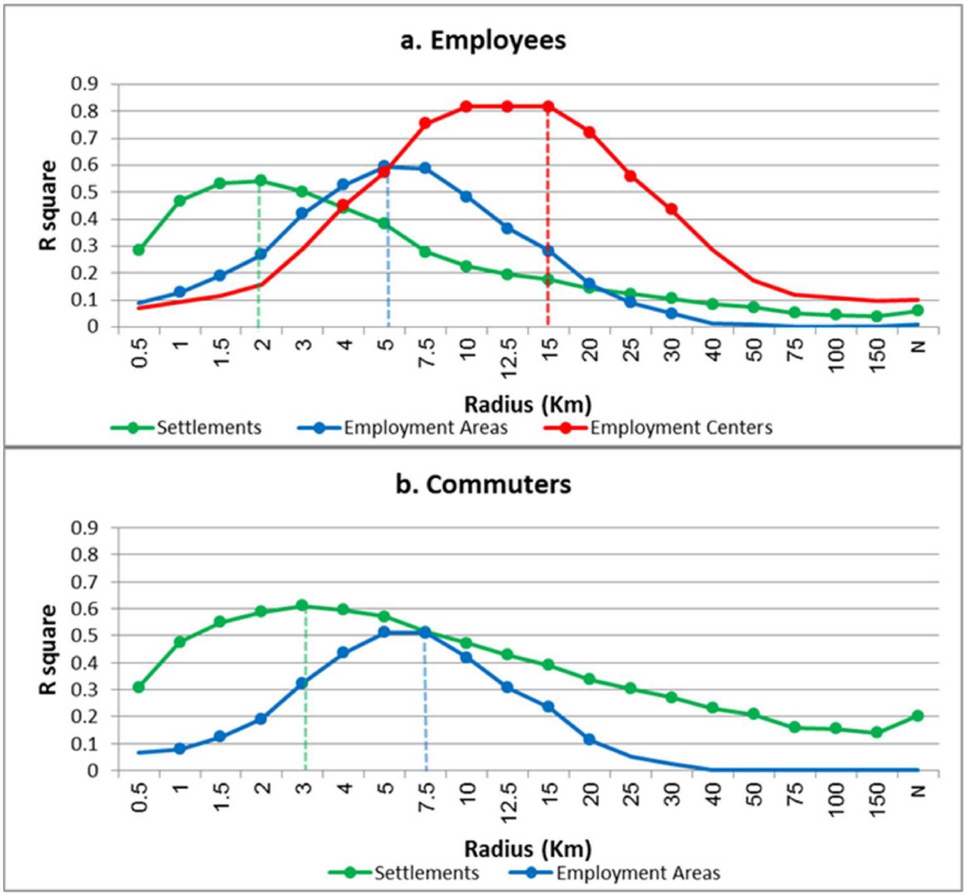

Fig. 5. Correlation coefficient (R^2) between average Integration values across spatial scales to the number of employees (a) and commuters (b); the green lines represent aggregation to the settlements level, the blue lines represent aggregation to employment areas and the red line represent aggregation to the main employment centers. The number of commuters to the main employment centers are not included because they contain most of their commuters in their territories (i.e., commuters that not included in their territories are very few). Only significant correlations ($p < 0.05$) are noted. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

scales (5–25 km) and factors 3, the green lines, highly correlate ($r > 0.69$) to the local-urban scales (0.5–4 km). This evidently illustrates the main transition between the spatial systems at the intersections between the factor lines: between 4–5 km from local to regional and between 25–30 km from regional to national spatial systems. However, it may be more appropriate in referring to 'transition zones' between spatial systems (as illustrated by the black circles at Fig. 4) that are characterized by gradual, rather than sharp transitions, as has been noted by Serra and Pinho (2013). It should be noted that the three exposed basic accessibility regimes are the outcome of intrinsic correspondence between accessibility variables only.

Tel Aviv is prominent within these three spatial systems, as can be seen in Fig. 3, with notable attraction due to its high level of accessibility potential across multiple scales. This aspect will be discussed later in the functional context (Section 3.2). In addition, it should be noted that a demarcation between center and periphery is observed with the accessibility being stable from a radius of 75 km and above (Fig. 3q–t) as also indicted by the high correlation ($r > 0.92$, $p < 0.01$) between the accessibility levels in those radii. This is a particularly salient quality of the high accessibility of the core region and exemplifies the dominance and stability of the core region on the national scale.

The following section aims to reveal the relationships between Israel spatial structures shown above to Israel functional aspects.

3.2. *From spatial systems to functional structures*

The examination of the functional aspect in Israel is based on data of the labor market at: (i) the settlement level (Fig. 2c–e, n = 953), (ii) continuous employment areas with more than 2500 employees (Fig. 2f, n = 53), (iii) continuous areas with more than 20,000 employees which are defined as the main employment centers (Fig. 2f, n = 11) (additional details in Section 2.3). Therefore, we obtained *three levels of functional divisions*. Then we examined the correspondence between the spatial accessibility systems (Section 3.1) to those functional divisions.

At first step of that examination, we tried to examine the coefficient of determination (R^2) between factor scores of PCA and PAF to number of employees and commuters, according to the three functional divisions noted above. We found pretty similar results between the two methods, when all of the factors are not provide good correlation to the aggregation of employees and commuters, except factors 3 who has low correlation coefficient ($R^2 \sim 0.27$) to the aggregation at the settlements level, and factors 2 who have low correlation coefficient to the aggregation at the employment areas/centers level ($R^2 \sim 0.32$). These results make sense because factor 3 represents local regime and factor 2 represents regional regime. However, although we found that the PCA and PAF analyses are useful for detecting boundaries between the spatial accessibility systems (Section 3.1). The low association between factor scores and the spatial distribution of employees leads us to examine the original values of accessibility, in order to ensure higher accuracy in determining the relevant scale for functional aspects.

Fig. 5 presents the coefficient of determination (R^2) between accessibility level across multiple spatial scales to number of employees (5a) and commuters (5b), according to the three functional divisions noted above and this reveals several points. In all functional divisions, employment and commuters are correlated to the accessibility level ($R^2 > 0.55$ and $R^2 > 0.57$, respectively), and notably for the main employment centers ($R^2 = 0.81$), while low correlations are identified for radii above 30 km. This may indicate a bound on accessibility to work. Likewise, correlations differ between accessibility in relation to different radii and from different functional divisions. This indicates that the functional divisions perform separately at different spatial scales. Therefore, the relevant spatial radius of accessibility for each functional division can be detected. Indeed, the highest correlation

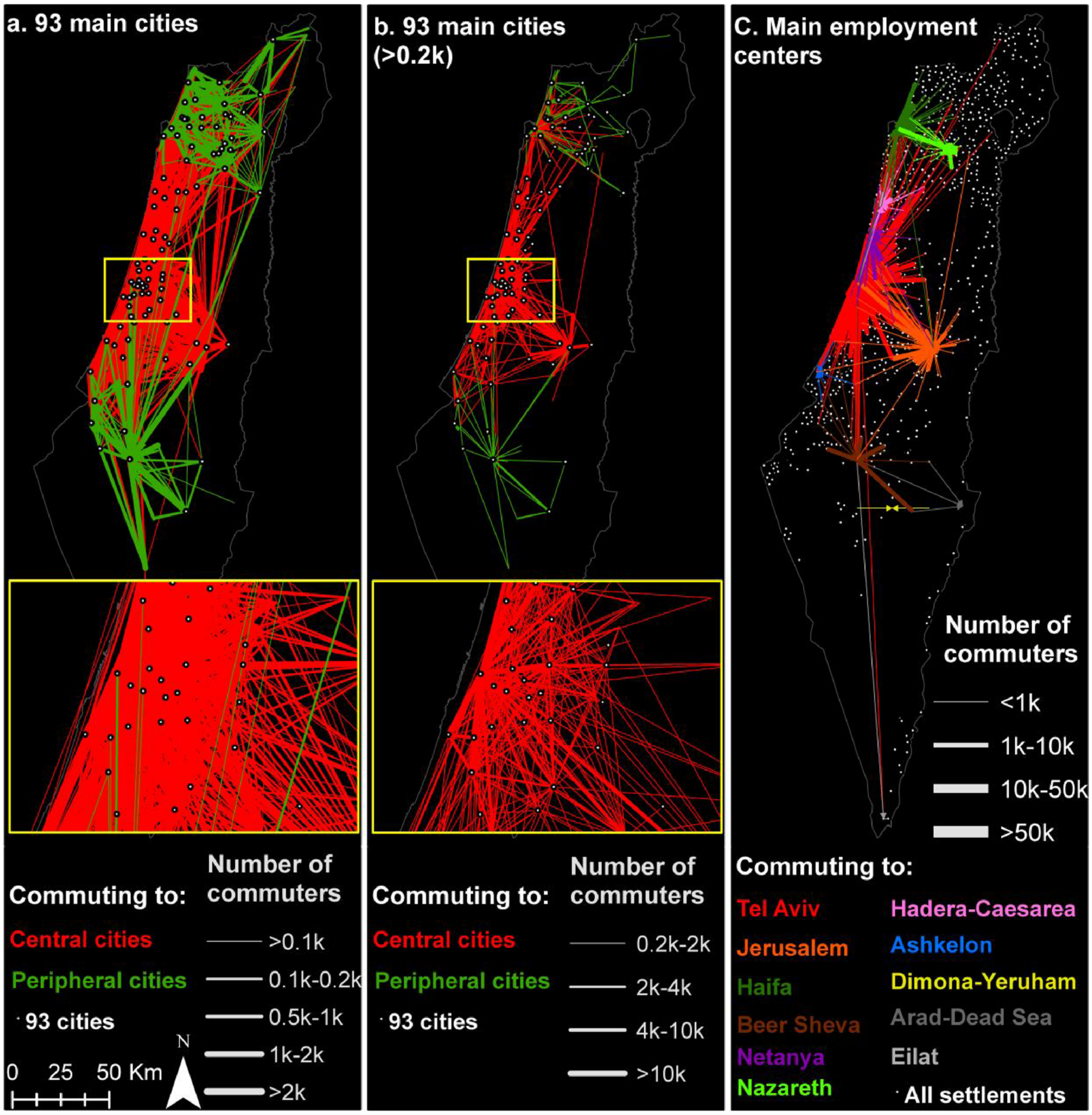

Fig. 6. The main commuting flows patterns in Israel: commuting flows to 93 main cities (a); significant commuting flows (> 0.2k people) to 93 main cities (b); commuting flows to the main employment centers (c); The yellow frame at figures (a) and (b) highlights the intensive commuting network in the Tel Aviv metropolitan area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

between spatial accessibility and local employment at the settlement level is at a radius of 2 km (Fig. 5a). The highest correlations between spatial accessibility and the spatial distribution of employment areas are found at 5 km, while the radius of 10–15 km and constitutes the dominant radius of accessibility for main employment centers (Fig. 5a). In regards to commuting patterns the maximum correlation is slightly higher at radius of 3 Km for local and radius of 7.5 Km for the regional (Fig. 5b). The local and the regional functional scales correspond to the local and regional spatial accessibility systems revealed in Section 3.1. These consistencies are also confirmed by visual comparison between: (i) settlements with more than 1000 employees (Fig. 2c) and/or more than 1000 commuters (Fig. 2e) to medium and high accessibility levels at radius 2 km (Fig. 3d); (ii) between employment areas (Fig. 2f) to medium and high accessibility levels at radius 5 km (Fig. 3g); and (iii) the main employment centers (Fig. 2f, > 20k) to medium and high accessibility levels at radius 10–15 km (Fig. 3i–k).

Investigation of commuting flows in the context of spatial analysis (Fig. 6) reveals that the core region is relatively well connected (compared to the periphery), especially the Tel Aviv metropolitan area (see also Fig. 2a) which is also characterized by dominant accessibility across all spatial scales (Fig. 3). In general, a denser structure was observed in the metropolitan areas, especially around the metropolitan nodes and with a much higher intensity in the Tel Aviv metropolitan area (the yellow frame in Fig. 6a, b). The total flows to the center are much higher than flows to the periphery (~90 % from total flows), where most of the flows of people to the center arrive from the center itself (~97 %). This point also valid for employees in the periphery with most of them travels within the periphery (~79 % from the commuters). In addition, only low flows exist from periphery to core (~10 % from all flows), and concomitantly from core to periphery (~2 % from all flows). These clearly indicate a bifurcation of the national system. These patterns are discerned by focusing only on substantial commuting flow patterns more than 200 people (see Fig. 6b, c). It seems that the isolated localities in the periphery (Fig. 2b, c) attract commuters (Fig. 2e) to a more a limited extent, and most of the employed persons (> 50 %) there work in their city of residence (Fig. 2d). Also, the commuting flow patterns imply that it may be more appropriate to consider the periphery in a regional context, in particular due to the negligible functional and geographic connection between the northern and southern peripheral regions (green flows in Fig. 6a. b). Therefore,

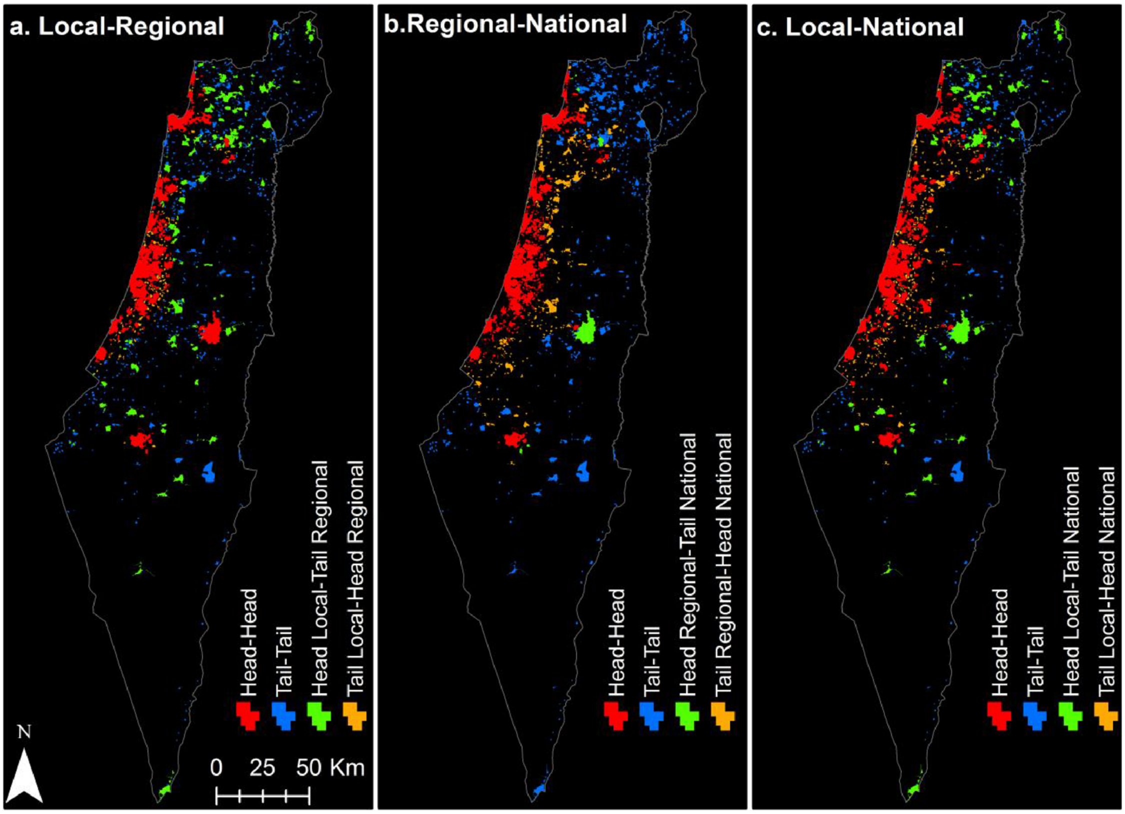

Fig. 7. "Head-Tail" clusters at the settlement level for (a) Local-Regional scale; (b) Regional-National scale; and (c) National-Local scale. The spatial-groups and the clusters color are corresponding to Fig. 8.

while the core area is characterized by kind of polycentric commuting structure, the periphery suffers from weaker commuting flows lacking a substantial functional structure.

This difference between functional behavior in the center and functional behavior in the periphery raises a hypothesis regarding Israel's functional structure is markedly dissimilar in the center versus the periphery. Indeed, it seems that national accessibility is fundamental in the separation between these two spatio-functional systems. In order to test this hypothesis, it is necessary to use a multi-scale examination in order expose differences between core and peripheral functional systems in which the former may function at multiple scales (local-regional-national) while the latter mostly functions at a local scale. This analysis may also provide insight about the relevance of scale and more specifically, which scale is more important, local, regional, national or some combination of them.

The stability of accessibility across scales was then investigated using the accessibility values for the settlement at local (2 km), regional (15 km) and national (N) levels, based on the maximum correlation between accessibility and functional performance for each spatial accessibility system (Fig. 5a). Analysis based on the principle of high/low clusters was adopted to characterize the level of accessibility of a settlement (high/ low) over a set of combinations of multi-scale pairs (local-regional; regional-national; local-national). Since accessibility levels of settlements for local and regional scales are characterized by heavy-tailed distributions, we adopt the principle of the *head/tail break classification* that deals with these types of distributions. This categorizes the data into "head" and "tail" for values above or below the mean, respectively (Jiang, 2013, 2015). This algorithm was applied for each accessibility value (local, regional and national) and resulted in two groups for each scale: the *head*- settlements with accessibility level above the mean, and the *tail*- settlements with accessibility level below the mean. Then, based on the results for each settlement we classified the settlements by clusters of "*head-head", "tail-tail", "head-tail"*, and "*tail-head*" according to the scale groups of "local-regional", "regional-national" and "local-national"[1] . The association of the obtained clustering with employees, population and commuters at the settlement level is dealt with in the following section.

The spatial patterns of the *"head-tail"* clusters are presented in Fig. 7 and their relationships to employees, commuters and population are presented in Fig. 8. This analysis exposes several essential points. The red clusters ("head-head") located in the center remain stable, i.e., the center is characterized by multi-scale high accessibility. Most of the small settlements in the periphery, with populations less than 3000, are unable to create sufficient accessibility at any scale ("tail-tail"), while larger peripheral cities and local municipalities are able to provide significantly higher local accessibility ("head local- tail regional/national"). The peripheral cities are limited to both low regional and low national accessibility and, therefore, function are limited to the local scale (Figs. 7b, 8b). Figs. 7c and 8c depict Israel's functional structure, where most cities in the center are characterized by "head-head" levels of accessibility with large population sizes, employees and commuters, while cities in the periphery having "head-tail" levels of accessibility with small to medium population sizes, employees and commuters. In contrast, small settlements in the center cluster into the "tail-head" group and have small populations, employees and commuters and their counterparts in the periphery belong to the "tail-tail" group as a result of low accessibility.

The *"head-tail"* analysis demonstrates that high local accessibility provides a base for functional activity which constitutes a measure for "critical mass" enabling higher potential functional activities, at least as reflected by employees and commuters (Fig. 81 and 2 respectively). The

[1] For example, for the group of "local-regional", the classification groups are *"head-head*" (head local- head regional), "*tail-tail*" (tail local- tail regional), "*head-tail*" (head local- tail regional), and *"tail-head*" (tail local- head regional).

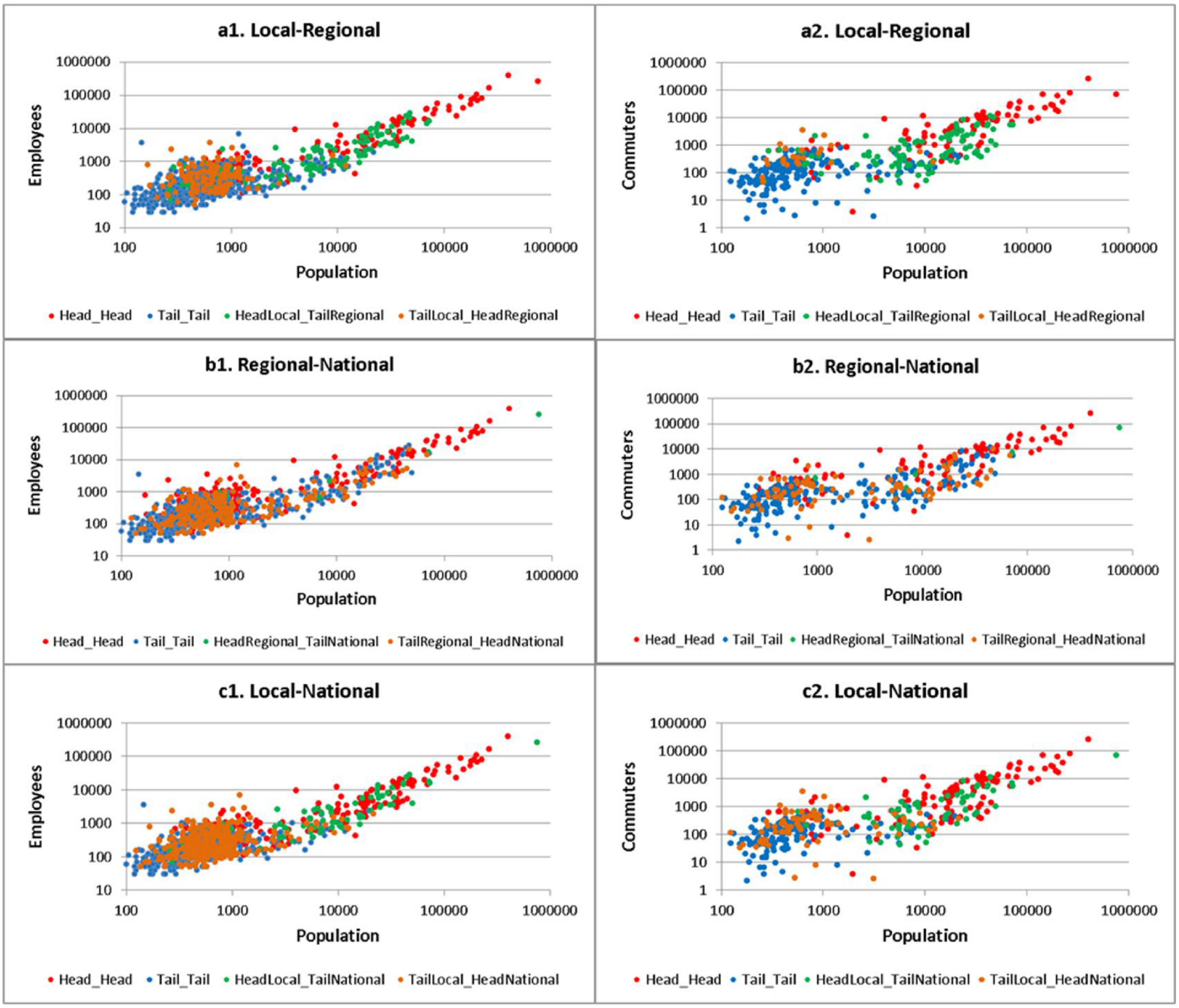

Fig. 8. "Head-Tail" clusters at the settlement level for (a1,2) Local-Regional scale; (b1,2) Regional-National scale; and (c1,2) Local-National scale; and their correlation to: population and employees (1) and population and commuters (2). The spatial-groups and the clusters color are corresponding to Fig. 7.

consequence of which is that without local accessibility it is almost impossible to reach high levels of functional activity. Nonetheless, low national accessibility limits the level of functional activity observed for medium and large cities are mainly characterized with high national accessibility.

4. Discussion

This study aimed to achieve a better understanding of the relationship of spatial accessibility and the formation of functional systems at different spatial scales in the Israeli spatio-functional national system. The results reported here indicate the emergence of three distinct spatial accessibility systems: the *local*, the *regional* and the *national* scales, that were identified through the implementation of two statistical techniques: PCA (Serra & Pinho, 2013) and PAF (Krenz, 2017b). Both methods provide similar results and allowed the determination and validation of the 'natural' border scales between the spatial accessibility systems. The *local* spatial system appears to have medium and high accessibility levels at radii of 1–4 km, highlighting large urban settlements or cities. The *regional* spatial system emerges from 5 to 25 km radii and is characterized by clusters of highly accessible urban regions with cities in isolated regions with only medium levels of accessibility. From the radius of 10 km the four major Israeli metropolitan areas appear with a clear dominance of the central Tel Aviv metropolitan area. The *national* spatial system begins to form by integration of the inter-metropolitan space (30 km) and continues to grow into a definitive core region (center) and obviously distinguishable from the periphery. From this, the national core-periphery structure is clearly identified by levels of accessibility with the demarcation between center and periphery is observed by the stable accessibility being from a radius of 75 km. High accessibility levels of the core region exemplifies the domination of the core region, and its cohesion across multiple scales.

Further examination reveals the relevant accessibility radius for the functional systems. Local systems seem to be constrained to approximately 2 km. For regional functional systems, the relevant scale of accessibility for the employment centers are in the range of 5 km–15 km for the main employment centers which comprises the main work force of the national economy. This scale is quite similar to the average commuting distance in Israel of approximately 19 km (ICBS- Israel Central Bureau of Statistics, 2008a). Moreover, local and regional functional scales correspond to the local and regional spatial accessibility systems. Further investigation of commuting flows reveals that the core region is relatively well connected with a densely packed network structure around the metropolitan nodes and, especially, in the metropolitan area of Tel Aviv (ICBS- Israel Central Bureau of Statistics, 2008e; Razin & Charney, 2015). By comparison, no substantial commuting flows were found within the periphery, as well as between periphery-core at the national scale, similar to findings about daily movements (Givoni, 2017). It seems that the isolated cities and settlements in the periphery attract commuters to a much more limited extent than the center. Also, the commuting flow patterns reveal that is more appropriate to consider the Israel periphery also in a regional context, as noted by Bar-El and Parr (2003b) and supported by reports of low daily movements between the north and the south peripheries (Givoni, 2017).

This study has revealed that the multi-scale accessibility level of settlements corresponds to their functional characteristics (employment location and commuting flows). Explicitly, the core region functions at multiple scales (local-regional-national) while the periphery mostly functions at a more localized scale. This approach may shed light on the general relation between local and national spatial systems (Pain, 2008) with respect to the stability of accessibility across local-regional-national scale. Finally, the local scale is crucial in defining the critical mass able needed to increase potential functional activities, yet, low regional-national accessibility limits the level of functional activity and vice versa.

Hence, the methodological framework used in this study and its findings are significant for several perspectives. First, the revealed 'natural' spatio-functional systems at different geographic scales in this study correspond with the typical spatial organization of functional activities that are found in developed countries, as well as with hierarchical structure of planning authorities in those states. These findings indicate at which geographical scale accessibility potential well correlate to actual functional performance (Batty, 2009). This reinforces the importance of accessibility analysis to define and characterize regional form and function (Wachs & Kumagai, 1973). Our *bottom-up* approach enables to examine the extent of local interaction between different parts (settlements) gives rise to a global (national) structure. Thus, this approach is comparable with the self-organization perspective of dynamical urban systems (Portugali, 2011). In other words, we are able to examine the spatio-functional structure from its basic units, such as roads and settlements, and it is the road system which alludes to the spatial divisions imposed by the emergent structure (Serra & Pinho, 2013; Serra, Gil, & Pinho, 2017). This perspective may expose contradictory findings from the official plan (Zhong et al., 2017) and allow the examination of the spatial divisions that are more suitable than the conventional approaches (Bar-El & Parr, 2003a; Pain, 2008).

Second, the results reported here imply that angular segment analysis is able to capture the core-periphery structure at the national space better than the measurements based on metric distance. This may be important and even crucial for studies in economic geography and spatial development research at the national level. Indeed, the case of Israel illustrates this very well with the core-periphery structure obtained from angular analysis being closely associated with the *Peripheriality Index* (ICBS- Israel Central Bureau of Statistics, 2008g) that is used for designing spatial policy and calculated by combination of proximity (metric) distance of local authority to all other local authorities (taking into account city size as a function of population) and distance for boundary of Tel Aviv District (economic heart). The metric accessibility alone yielded a different result (see in: ICBS- Israel Central Bureau of Statistics, 2008g). From wider scientific perspective, this finding supports the superiority of angular distance for the analysis of the conjunction between spatial configuration and movement flows not only at the urban scale (Hillier & Iida, 2005; Omer & Kaplan, 2018) but also at the regional and national scales (Serra & Hillier, 2018)

Third, regarding multi-scale accessibility, especially the stability and the dominance of the center across scales, validates a regional-national perspective to support the theory of *pervasive centrality* found in cities (2012a, 2012b, Hillier, 2009; Omer & Kaplan, 2018), according to which centrality functions diffuse throughout the network at all scales. The robustness of the multi-scale perspective indicates that settlements can be characterized by various levels of accessibility at various spatial scales[2] . This issue may have important implications for planning policy across all spatial levels - local, regional and national (Asif et al., 2014). Thus, for example, it is possible to determine where an area may have potential to expand its level of influence to a higher level, from the local to the regional, for example.

To summarize, we have expanded the understanding of spatio-functional structures and which constitutes a vital step towards strategic spatial planning in Israel (Asif et al., 2014) and in other countries. The outcomes of this study, regarding to the relationships and the boundaries of influence for various divisions of functioning across distinct spatial scales, constitutes an important component in this respect. Moreover, the use of space syntax methodology as an analytic design tool (Karimi, 2012) may be a powerful approach in examining planning scenarios (Marcus et al., 2010; Raford & Ragland, 2006), assessment of urban area expansion (Xia, Zhang, Wang, & Yeh, 2019) and investigation of population growth scenarios with concomitant infrastructure implementation at a national scope (Parham et al., 2017) are compatible with these needs.

5. Conclusions

This study aimed to reveal the emergence of distinct spatial accessibility systems and their relation to the spatial distribution of functional systems, from local levels up to the national scale. Using angular segment analysis based on the space syntax methodology, the spatial accessibility (integration measures) of the entire paved road network of Israel at various of spatial scales was analyzed. Also, the functional aspect in Israel was evaluated with several variables including population size, employees, commuters and main commuter flows. Subsequently, the associations between spatial accessibility and functional indicators across different spatial scales were examined.

The results expose three spatial accessibility systems of local (< 4 km), regional (5–25 km) and national scale (> 30 km). Further, a significant correspondence exhibits transitions between local and regional spatio-functional systems. A significant correlation between local (2 km radius) accessibility levels of settlements with the number of employees and commuters and the regional (10–15 km radius) accessibility is highly correspondence to the emergence of the main employment centers. As part of those centers, particularly noticeable the dominant functional system of the four metropolitan areas. A detailed examination of the main commuting flow patterns reveals that the core region is relatively well connected, especially, around the main metropolitan's centers. In contrast, no substantial commuting flows were found within the peripheral areas, as well as between periphery and core regions. This functional structure was found corresponded to the multi-scale accessibility levels of settlements. Based on these findings, it is concluded here that the core region functions at multiple scales (local-regional-national) while the periphery functions essentially at a more limited local scale. This national accessibility analysis reflects well the separation between the two spatio-functional systems.

These findings reinforce the importance of accessibility analysis as an indicator for defining and explaining the functional organization at the urban, regional and national scales as well as the abilities of space syntax methodology in this respect. Various aspects discussed here indicate the importance of nation-wide spatio-functional analysis to assist long-term strategic spatial planning for Israel.

Further work is needed in order to expand the examination of accessibility at national scales. First, the effects of rail transportation should be considered[3] (Lerman & Lebendiger, 2017). Second, changes in accessibility across time (Kwok & Yeh, 2004; Xia et al., 2019) need to be examined. Third, the methodology presented here may improve by using other relevant centrality measures, especially to detect and define the emergent boundaries of communities (Fortunato, 2010) and core-

[2] For example, two cities with the same level of local accessibility may differ in their national accessibility levels, and therefore their growth potential is completely different.

[3] It should be note again that in Israel only 0.6 % from the journeys to work in 2008 carried out by the train. In 2016, 3.4 % from the journeys to work carried out by the train (Bank of Israel, 2018).

periphery (Rombach, Porter, Fowler, & Mucha, 2014) as defined by network centrality. Fourth, higher resolution and richer data for the commuting flows, like cellular network or GPS surveillance, may provide socio-spatial data along with the ability to conduct accurate analysis concerning the accessibility-employment relations (Zhou, Chen, Yeh, & Yue, 2019).

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