Proceedings of the Ninth International Space Syntax Symposium
Edited by Y O Kim, H T Park and K W Seo, Seoul: Sejong University, 2013

DEFINING A STRATEGICAL FRAMEWORK FOR URBAN PEDESTRIANIZATION PROJECTS:

Assessment of walkability in 3 urban squares in Istanbul

110

Ayse Sema Kubat
Istanbul Technical University
e-mail : kubat@itu.edu.tr
Ozlem Ozer
Istanbul Technical University
e-mail : oslem.oser@gmail.com
Ayse Ozbil
Okan University
e-mail : ayse.ozbil@okan.edu.tr

Abstract

There has been a growing interest in the transformation of major urban squares in Istanbul in recent years. This heightened trend in the urban renewal of prominent areas within the city has led to multiple pedestrianization projects aimed to revitalize urban cores in terms of infrastructure and pedestrian activity. Despite their strategic schemes, these proposed projects lack an objective methodology to implement systematically at various scales. This paper focuses on the walkability of 3 historical urban squares in Istanbul by analyzing their street configuration and land use compositions and comparing it with the levels of pedestrian movement. The main objective of this study is to determine the existing relationship between space allocation and pedestrian activity and to assess the efficiency of proposed pedestrianization projects developed by local authorities for these areas. Overall, the analyses presented in this study emphasize the importance of measures of street connectivity in walkability studies. It is shown that street network configuration; measured using both metric and directional connectivity measures at the road-segment scale is strongly associated with pedestrian movement when controlling for land use compositions at the parcel-level. Based on the spatial analysis and statistical models produced for the research area, a pedestrian-oriented strategical framework that takes into account the existing spatial configuration, parcel-based land-use compositions, as well as pedestrian movement distributions within the areas is proposed for the study areas and their surroundings. With its systematic methodology, efficient spatial models, and strategical approach, this study is anticipated to be used as a unique design framework for prospective urban design and pedestrianization projects for Istanbul.

Keywords: *walkability, pedestrianization of urban centers, street connectivity, land use composition, pedestrian movement, Istanbul*

Theme: *Urban Space and Social, Economic and Cultural Phenomena*

Introduction

This study aims to develop a strategic framework underlying prospective pedestrianization projects for historical urban squares in Istanbul. It is based on the walkability of these squares established by the link between street configuration, land-use compositions and pedestrian movement. There has been a growing interest in the transformation of major urban squares in Istanbul in recent years. This heightened trend in the urban renewal of prominent areas within the city has led to multiple pedestrianization projects aimed to revitalize urban cores in terms of infrastructure and pedestrian activity. Despite their strategic schemes, these proposed projects lack an objective methodology, failing to be implemented systematically at various scales. This study is a cross-sectional observational study specifically designed to examine the extent to which objectively measured urban form characteristics of a local neighborhood, namely street connectivity and land-use measures, affect the walkability of the neighborhood. The objectives of this study are two-folds. First; this paper analyzes three historical urban squares in Istanbul in terms of street configuration, land use compositions and pedestrian movement to determine the existing relationship between space allocation and pedestrian activity. Second; it then describes how theoretical findings can be built back into practice by developing a pedestrian-oriented design framework for one of the urban squares and its surroundings. Consideration is given to future developments and applications of walkability-related measures that would offer fine-grained design rules for pedestrianization projects developed by local authorities.

This paper is part of a larger research project that comprises both walkability and wayfinding research for developing a pedestrian-oriented urban regeneration strategy. It should be noted that the proposed framework in this paper is intended to be complemented further with additional findings of the main study.

Measuring walkability

Researchers in transportation, urban design, and planning have sufficiently documented associations between neighborhood design and pedestrian activity. Factors that influence walking are primarily based on two fundamental aspects of urban form: proximity (distance) and connectivity (directness of traveled route) (Frank 2000). Proximity relates to the distance between trip origins and destinations. Proximity is measured by two urban form variables. The first is density, or compactness of land uses. Density is thought to shape pedestrian activity by bringing numerous activities closer together, thus increasing their accessibility from trip origins (Cervero and Kockelman 1997; Krizek 2003). It is suggested that people are willing to use slower modes of travel, such as walking, for shorter distances, especially if many trips can be chained (Frank and Pivo 1994; Marshall and Grady 2005). The second component of proximity is land use mix, or the distance between or intermingling among different types of land uses, such as residential and commercial uses. Similarly, land-use mix increases accessibility by increasing the number of available destinations within walking range. It is argued that commingling of offices, shops, restaurants, residences and other activities influences the decisions to walk by making it more convenient to walk to shops or to get to work (Cervero 2002; Rodriguez and Joo 2004).

Whereas proximity considers airline (crowfly) distances between origins and destinations, connectivity characterizes the directness of travel between households, shops and places of employment, and the number of alternative route choices within street network (Saelens et al. 2003). The connectivity of street networks increases accessibility in two ways. First, it makes it more likely that a short or more direct route is available for any given pair of origin and destination. Second, the more the length of streets in a given area, the greater the number of frontages, and thus of destinations, that are likely to be available at walking range. Potentiality, defined as the availability of accessible streets and destinations offered by the urban fabric, is significantly related to pedestrian travel. Destinations are certainly an aspect of land-use, but their number is generally proportional to the street length accessible within a walking distance. Fine-grained urban networks of densely interconnected streets improve transit and pedestrian travel by providing relatively direct routes, thus reducing the distance between origins and destinations.

Prevalent measures of connectivity within the literature have been limited to average measures of street networks, such as block length (Cervero and Kockelman 1997), block size (Hess et al. 1999; Song 2003), intersection density (Reilly 2002; Cervero and Radisch 1995), percent four way intersections (Cervero and Kockelman 1997; Boarnet and Sarmiento 1998), street density (Handy 1996; Mately et al. 2001), connected intersection ratio (Song 2003), and link node ratio (Ewing 1996). Apart from average measures of street density, some studies have investigated the underlying differences of street types, such as the distinctions between traditional vs. suburban and grid vs. cul-de-sac, to show a statistically significant relationship between street design with a grid-like geometry and increased frequency of walking trips (Shriver 1997; Greenwald and Boarnet 2001; Handy 1992; Rajamani et al. 2002). While most of these studies show positive associations between measures of connectivity and walking, recent papers point out that many of these positive associations are weak, even when statistically significant (Handy 2005; Oakes et al. 2007; Rodriguez et al. 2008). The foregoing findings also underline the multi-collinearity between such measures, hence the ambiguity of specific recommendations with regard to street network design. A number of studies have attempted to improve the explanatory power of street network design by developing composite variables that account for multiple dimensions of urban form, such as the "Pedestrian Environmental Factor” (Parsons Brinkerhoff Quade and Douglas Inc. et al. 1993) or “walkability index” (Goldberg et al. 2007).

There is, however, a more refined analysis which can differentiate between well and less well connected road segments and streets within a given area, whether it is a grid, a curvilinear pattern or a cul-de-sac. This group of studies, associated with space syntax (Hillier 1996; Peponis and Wineman 2002), takes a configurational approach. This involves measuring the accessibility of all parts of a network under consideration from each individual street element. The intent is to provide a generalized description of spatial structure and connectivity hierarchy without evoking information about land use or making assumptions about desirable or typical trips. In the case of space syntax, particular attention is given to the number of direction changes that are needed in order to move from one location to another. The claim that the ordering of connectivity, measured by direction changes, plays an important role in determining the distribution of movement is consistent with research findings in spatial cognition which suggest that direction changes, as an aspect of configuration, are related with the cognitive effort required to navigate through an area (Bailenson et al. 2000; Crowe et al. 2000; Hillier and Iida 2005; Jansen-Osmann and Wiedenbauer 2004; Montello 1991; Sadalla and Magel 1980). The choice of connectivity measures is critical. It affects the grain of theories regarding the relationship between network design and functional consequence, including the impact of network design on walking. Measures that emphasize the average properties of areas can be useful in supporting general guidelines and policies, but cannot inform design decisions about alternative street alignments or alternative ways of fronting and orienting developments. The connectivity measures applied in this research (Peponis et al. 2008) offer a systematic framework through which to evaluate street connectivity from two points of view: metric accessibility and density on the one hand, and directional accessibility on the other. The two measures are discussed fully in the next section.

Using GIS data to examine movement patterns

The above-described walkability components of proximity and connectivity can be readily utilized using GIS methods. The use of GIS is still somewhat new to the Turkish urban design context. GIS has primarily been used in urban planning and transportation planning practice, estimating average regional urban form characteristics. However, utilizing GIS data to capture fine-grained land-use and design aspects of urban form is essential for understanding travel impacts of small-scale place-oriented projects. This study is built upon measures of segment-based connectivity measures implemented on a GIS platform and land-use attributes acquired using GIS street network representations. A detailed overview of the dataset is presented below.

Defining Connectivity

Segment-based connectivity measures applied in this research (Peponis et al. 2008) offer a systematic framework through which to evaluate the urban fabric in terms of its potentiality (density of streets) and structure (directional bias based on configuration). The analysis is based on standard segment-based representations of street networks according to street center-lines. The unit of analysis is the road segment. Road segments extend between choice nodes, or street intersections at which movement can proceed in two or more alternative directions. Road segments may contain one or more line segments. A line segment is the basic unit of the map drawn and is always defined as a single straight line. Thus, the analysis treats the unit of analysis (the road segment, for which the individual values are computed) and the unit of computation (the line segment which provides the base metric for values) as different entities. Figure 1 illustrates the new unit of analysis by clarifying the difference between road segments and line segments.

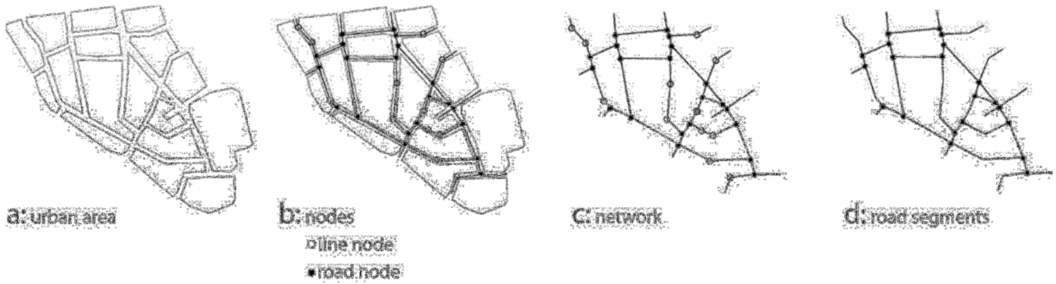


Figure 1 Definition of line segments and road segments. Source: Peponis et al. 2008.

Metric reach captures the density of streets and street connections accessible from each individual road segment. This is measured by the total street length accessible from each road segment moving in all possible directions up to a parametrically specified metric distance threshold. *Directional reach* measures the extent to which the entire street network is accessible with few direction changes. This is measured by the street length which is accessible from each road segment without changing more than a parametrically specified number of directions. While metric reach extends uniformly along the streets surrounding a given road segment, directional reach may extend much less uniformly, because it is sensitive to the shape and alignment of streets, not merely to their density. The connectivity measures used in this paper are inherently parametric, in that one can vary what rotation angle counts as a direction change or what walking threshold is used to measure the catchment area associated with each individual road segment. The decision to include these measures bears on the relationship between urban planning and urban design. Urban planning is oriented towards principles of general applicability and tends to be concerned with the average or aggregate properties of areas. Urban design must, by definition, address the fine grain of specific contexts. It is concerned with the internal structure of areas and with the way in which street layout impacts the nature, orientation and performance of building developments for which it provides the context. Walking is, after all, a pre-eminently context-dependent activity and one which occurs according to the fine grain of environment as well as according to its larger scale structure. That is why appropriately discriminating measures of street connectivity are essential to better design for walkability.

Sample Design

According to 2012 census estimates, Istanbul has a population of 13.9 million people, and is among the largest cities in the world by population within city limits (Turkish Statistical Institute 2013; Mossberger et. al. 2012). Three urban squares that are on the Municipality's agenda for pedestrianization were selected as study areas (Figure 2). These districts lie within the environmentally diverse but demographically homogenous western section of the city. The first area, Sultanahmet Square, is the heart of historic Istanbul and a popular sightseeing area. Embedded within a rich cultural and historical heritage, Sultanahmet district is one of the major sight-seeing areas for tourists and natives alike. The second area is Beyazit Square, which is situated in the historical peninsula between Istanbul University's main gate and the Grand Bazaar. The third area, Taksim Square which is considered the heart of modern Istanbul, is a major tourist and leisure district famed for its restaurants, shops, and hotels.

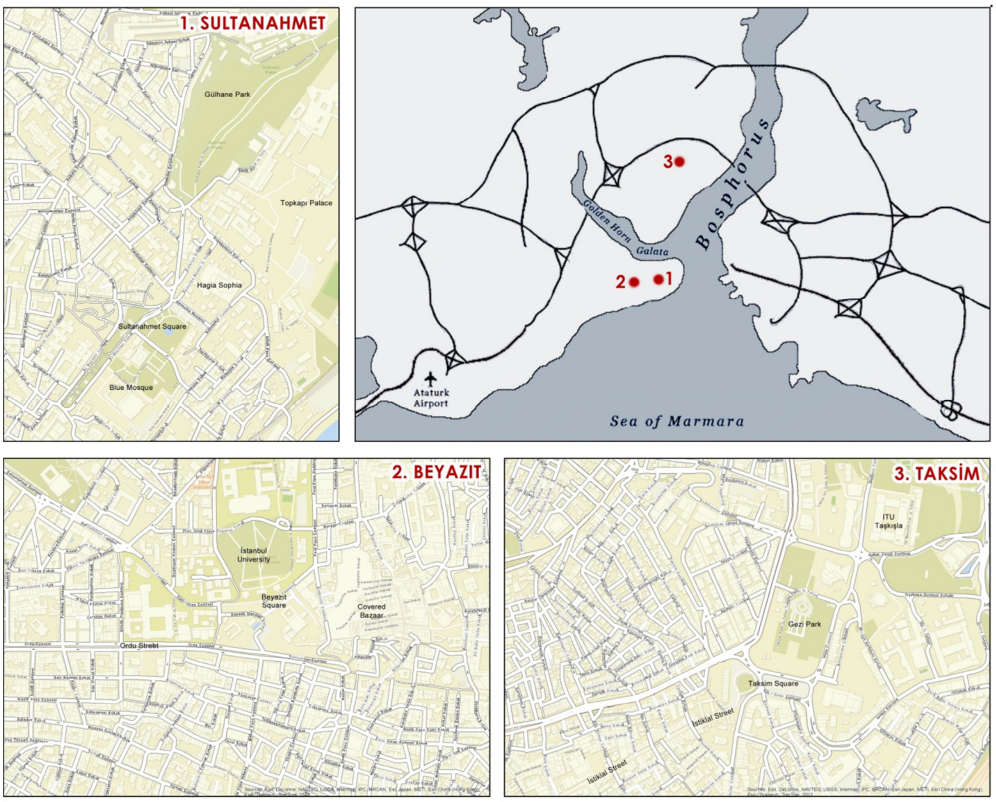


Figure 2 Selected study areas and their locations on the map of Istanbul.

Connectivity Patterns

To assess the street connectivity patterns, the entire street network of Istanbul Metropolitan area was analyzed using the Streetmap of 2010. In this research freeways were excluded since they do not factor in pedestrian movement. Metric reach was computed for 1, 0.5 and 0.25 mile walking distance thresholds. Directional reach was computed for 0 direction changes subject to a 20° angle threshold. Computing directional reach for 0 direction changes is equivalent to measuring the length of the axial line that covers the center of a road segment. 20° was used as a threshold angle to make the analysis more sensitive to the distinction between linear and curvilinear systems. Figure 3 shows the street networks of the pilot areas embedded within the surrounding 1-by-1mile grid, coded according to 0-directional reach. Even in the absence of any other design information, such as street width, a hierarchy of streets emerges based on the intrinsic relational properties of the networks. In Sultanahmet directional accessibility model reflects a fragmented pattern of continuous, straight streets, whereas, in Beyazit and more so in Taksim, a pattern of grids are captured, illustrating the sub-areas within the larger context. Hence, these comparative images show that road segment-based connectivity measures discriminate well between the spatial configurations of 3 areas that are located in proximity to each other. While the selected areas display a similar typological street network pattern, they differ significantly in terms of their directional accessibility patterns.

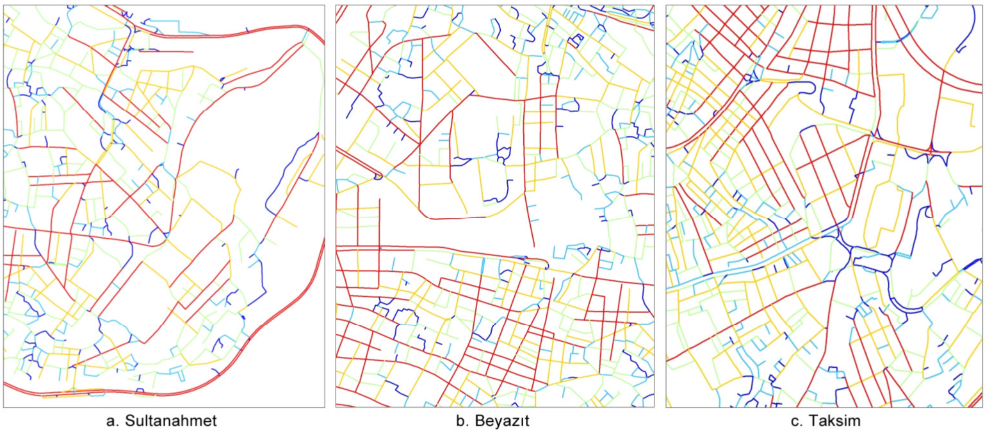


Figure 3 Street networks captured within the pilot areas. Streets are color-coded at the same scale according to 0-directional reach (20o). Red colors reflect higher values, while blue colors show lower values. Thus, colors are based on the ordering of individual streets within the entire street network according to their differentiation of internal spatial structures.

Land-Use Patterns

In order to address how land-use patterns at the road segment scale may contribute to culture of walking, it was incumbent to study land-use compositions within the study areas. The distribution of parcel-based land-uses was investigated to demonstrate the ways in which land-use patterns vary between the selected areas. Figure 4 illustrates parcel-based land-use compositions in pilot areas. Illustrative data reflect both similarities and differences in land-use patterns among the areas. Sultanahmet and Beyazit are primarily non-residential (mostly retail, offices and institutional uses) districts with relatively lower-density residential developments located in their southern sections. On the contrary, Taksim is dominated by residential uses with a number of institutional uses scattered in the area. However, relying solely on land-use classification maps is likely to underestimate the prevalent trait common to all 3 areas, where ground floors of most residential uses are devoted to small retail shops. Particularly in Taksim ground-floor retail contributes significantly to increased pedestrian movement densities by generating a “passing trade”.

Parcel-based data were categorized into residential (single and multi-family) and non-residential (office, retail, institution, recreation, industrial) for the purpose of distinguishing between the effects of each on the distribution of movement. Gross densities of land-use were calculated as a linear measure at the road segment scale by computing residential and non-residential building square meter associated with each individual segment, and relativized by segment length: square meter of development per 100m of street length.

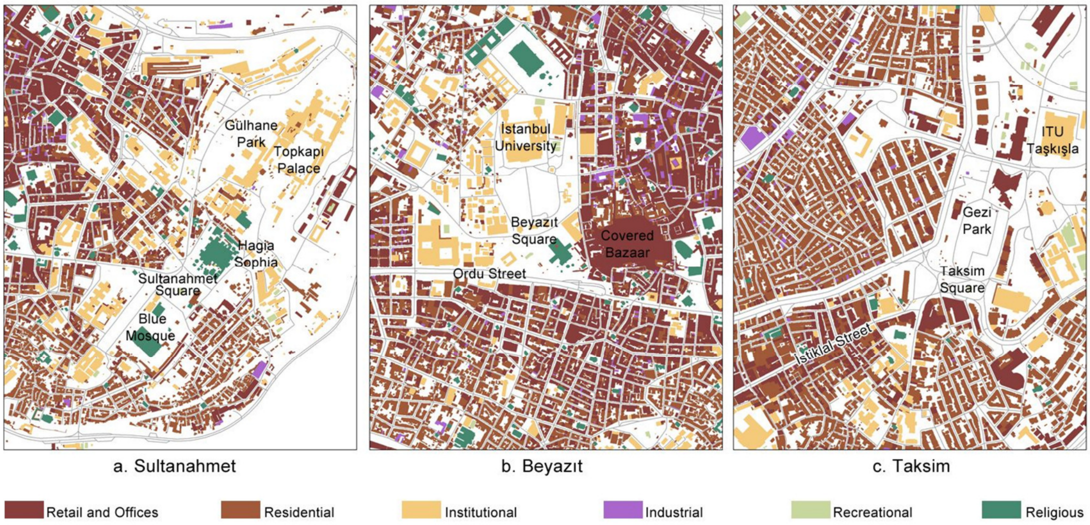


Figure 4 Distribution of parcel-level land-use in 3 areas.

Pedestrian Movement Data Collection

Pedestrian count data were systematically collected in the three study areas during March 2013. Pedestrian densities were observed in 116 gates within the area. The observation gates were selected to be representative of differing spatial hierarchial qualities. We completed 10 minutes of observation for each gate, distributed over 3 different time periods. We observed 90 road segments in Sultanahmet, 83 gates in Beyzait, and 47 gates in Taksim. The median density of moving pedestrians per 100 meters is 8.4, 13.7, and 14.6 for Sultanahmet, Beyazit, and Taksim respectively, while the corresponding means are 14.3, 19.3, and 29. Figure 5a shows the three areas and marks the observation sets for each area. Figure 5b shows graphically the distribution of movement densities using circles of different diameters for Sultanahmet, Beyazit and Taksim.

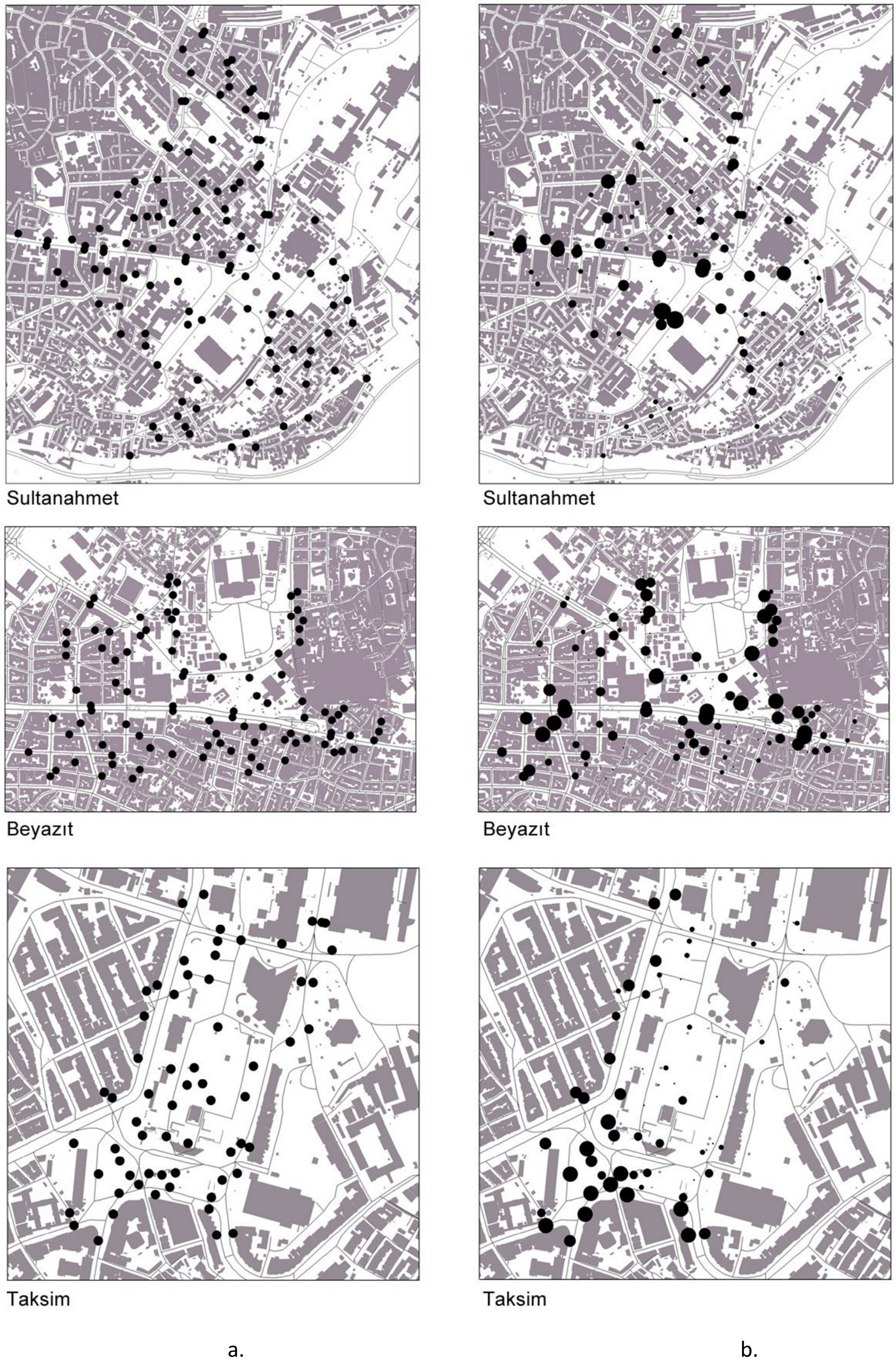


Figure 5 a) Location of pedestrian observations, and b) Observed pedestrian densities.

Spatial Layout as the Determinant of Movement Patterns

On the basis of this data set, multivariate models were produced to investigate the extent to which street connectivity and land use density explain the distribution of movement per street segment. In order to judge how walking thresholds affect results, all areas were analyzed using metric reach for 1-mile, 0.5-mile and 0.25-mile walking ranges. Table 1 summarizes the results of multivariate regressions run for 3 ranges separately. While metric reach is statistically significant across all models, the highest standardized coefficient is obtained for 0.25 mile range. At meso-scale (½ of a mile) metric reach still continues to be a reasonably significant predictor, though with lower effect size. The effect becomes weaker when we look at 1 mile radius, because the extra effort to walk a considerably longer distance begins to overpower the positive influence of connectivity. This supports the findings of various studies which suggest that acceptable pedestrian walking distances are set at between 0.25 mile and 0.5 mile, with 1 mile being the upper limit (JHK and Associates 1987). Thus, based on these inferences it can be argued that 0.25-to-0.5 mile should be promoted both as the distance to model pedestrian context within neighborhoods and as metric threshold for calculation of Reach in the characterization of street networks with the particular aim to influence the decision to walk.

Table 1 Parameter estimates for multivariate regressions estimating the frequency of use of road segments for all used paths considered as a single set –comparing results using metric reach for quarter, half and one mile.

Model for 1-mile walking			Model for 0.5-mile walking			Model for 0.25-mile walking		
	B	std β		B	std β		B	std β
constant	1.14	–	constant	0.36	–	constant	0.23	–
Reach (1mile)	0.02	0.23	Reach (0.5 mile)	0.10	0.40	Reach (0.25 mile)	0.42	0.49
0-Directional Reach (20^o)	0.92*	0.15*	0-Directional Reach (20^o)	1.13	0.19	0-Directional Reach (20^o)	1.53	0.26
total land-use m^2 /100m	0.00	0.17	total land-use m^2	0.00	0.16	total land-use m^2 /100m	0.00	0.17
N=220			N=220			N=220		
R^2	0.13		R^2	0.24		R^2	0.32	
R^2 adjusted	0.12		R^2 adjusted	0.23		R^2 adjusted	0.31	

Note: Numbers in bold= significant difference (p<0.01); * significant difference (p < 0.05).

Linear models were produced for the frequency of use of all road segments merged into a single set for 0.25 mile range to identify the statistical significance levels of all variables and to capture the unique contributions of connectivity measures to the overall model. Table 2 summarizes the results for multivariate regressions estimating the natural logarithm of pedestrians relativized by 100 meters. Each column shows, first, the predictability of the model with only the connectivity measures, and then, in turn, the effect of adding land-use measures to the model.

The results of analysis of three areas as a single set suggest that the impact of street connectivity on the distribution of movement is quite consistent across models. Metric and directional reach together explain around 30% of the variation in movement (at a 99% level of confidence). In all models, the coefficients for metric and 0-directional reach are positive and statistically significant. In other words, the highest levels of pedestrian movement were observed in metrically most connected areas and in street networks with more direct connections. These results suggest that both the shape and alignment of streets and their density over a given area is significantly associated with the choice to walk. Hence, it can be argued that street networks with denser intersections and more linear alignments of road segments support walking behavior. Consistent with theory, pedestrian movement levels are also sensitive to land-use densities. The positive coefficients of total and non-residential building square feet at the street segment scale suggest that movement levels increase with higher development densities. The negative effect sign of residential land-use variable might be suggestive of the fact that since the three areas are highly touristic places, residential developments within these districts fail to support walking behavior due to decreased number of available destinations within walking range.

Table 2 Parameter estimates for multivariate regressions estimating the frequency of use of road segments for all used paths considered as a single set using metric reach for quarter mile.

	Connectivity measures			+ Land-use measures					
				Aggregate land-use			Disaggregate land-use		
	B	t	std β	B	t	std β	B	t	std β
constant	–	1.08	–	–	0.97	–	–	4.29	–
Reach (0.25 mile)	0.43	8.71	0.50	0.42	8.61	0.49	0.29	5.68	0.34
0-Directional Reach (20^o)	1.50	4.42	0.25	1.53	4.60	0.26	2.30	6.82	0.39
total land-use m^2 /100m	–	–	–	0.00	3.09	0.17	–	–	–
residential m^2 /100m	–	–	–	–	–	–	-0.01	-5.77	-0.37
non-residential m^2 /100m	–	–	–	–	–	–	0.00	2.71	0.14
N=220									
R^2	0.29			0.32			0.41		
R^2 adjusted	0.28			0.31			0.40		

Note: Numbers in bold= significant difference (p<0.01); * significant difference (p < 0.05).

In order to better understand the distribution of pedestrians in each area, previous models were re-run by considering each area separately. Tables 3-5 present the individual impacts of connectivity and land use variables on the distribution of movement in Sultanahmet, Beyazit, and Taksim. The results of multivariate models demonstrate the effect of street connectivity on space use. While in Taksim metric reach appears to be the only significant correlate of pedestrian movement (at a 99% confidence level), in Sultanahmet and Beyazit the relative effect size and significance level of directional accessibility is considerably higher than metric accessibility. In fact, the sign and significance of the coefficient remains consistent even after the inclusion of land-use measures. This finding supports the argument that direction changes are critical to the way in which environments are understood, particularly when walking in unfamiliar surroundings, and that people orient themselves with respect to frames of reference that are as linear as possible (Moeser 1988; Conroy-Dalton 2003). Therefore, it would appear that in addition to street density, spatial structure based on directional bias is indeed implicated in the way in which street networks function to support the way people use and understand urban environments.

When the three areas are analyzed individually, land-use density at the road segment scale does not appear to be as strong a correlate of movement as street connectivity. In Sultanahmet and Beyazit the coefficients for the residential development density are negative and statistically significant (at a 99 per cent level of confidence), which is in parallel with earlier results of individual areas considered as a single set. The negative effect sign of residential density might be indicative of the fact that increased number of residential uses along a road segment, especially in higher-density commercial areas, fail to attract pedestrians failing to act as target destinations for pedestrian trips. Among three areas only in Beyazit the non-residential land-use variable coefficient produces the expected positive sign. This variable is no longer significant in the linear models of movement for the remaining two areas. In Taksim, which has a relatively uniform and even pattern of land-use dominated by residential uses, land-use variables (both aggregate and disaggregate) fail to correlate with pedestrian movement (Table 5). This suggests that land-use variables might have a stronger influence on walking behavior in areas with increased spatial inter-mixing among development densities.

Table 3 Parameter estimates for multivariate regressions estimating the frequency of use of road segments in Sultanahmet district using metric reach for quarter mile.

	Connectivity measures			+ Land-use measures					
				Aggregate land-use			Disaggregate land-use		
	B	t	std β	B	t	std β	B	t	std β
constant	–	1.59	–	–	1.71	–	–	3.88	–
Reach (0.25 mile)	0.29	3.42	0.31	0.27	2.96	0.28	0.20*	2.27*	0.21*
0-Directional Reach (20^o)	3.33	4.48	0.41	3.27	4.37	0.40	3.78	5.37	0.46
total land-use m^2 /100m	–	–	–	0.00	0.85	0.08	–	–	–
residential m^2 /100m	–	–	–	–	–	–	-0.01	-3.97	-0.34
non-residential m^2 /100m	–	–	–	–	–	–	0.00	0.54	0.05
N=90									
R^2	0.33			0.33			0.44		
R^2 adjusted	0.31			0.31			0.41		

Note: Numbers in bold= significant difference (p<0.01); * significant difference (p < 0.05).

Table 4 Parameter estimates for multivariate regressions estimating the frequency of use of road segments in Beyazit district using metric reach for quarter mile.

	Connectivity measures			+ Land-use measures					
				Aggregate land-use			Disaggregate land-use		
	B	t	std β	B	t	std β	B	t	std β
constant	–	3.06	–	–	1.86	–	–	4.95	–
Reach (0.25 mile)	0.23	2.87	0.33	0.27	3.64	0.39	-0.00	-0.04	-0.01
0-Directional Reach (20^o)	1.05*	2.24*	0.26*	1.28	2.92	0.31	2.35	5.47	0.57
total land-use m^2 /100m	–	–	–	0.00	3.78	0.38	–	–	–
residential m^2 /100m	–	–	–	–	–	–	-0.01	-5.14	-0.73

non-residential m^2 /100m	–	–	–	–	–	–	0.00*	2.16*	0.20*
N=83									
R^2	0.11			0.24			0.44		
R^2 adjusted	0.09			0.22			0.41		

Note: Numbers in bold= significant difference (p<0.01); * significant difference (p < 0.05).

Table 5 Parameter estimates for multivariate regressions estimating the frequency of use of road segments in Taksim district using metric reach for quarter mile.

	Connectivity measures			+ Land-use measures					
				Aggregate land-use			Disaggregate land-use		
	B	t	std β	B	t	std β	B	t	std β
constant	–	-5.53	–	–	-5.90	–	–	-2.86	–
Reach (0.25 mile)	1.05	11.13	0.86	1.06	11.53	0.86	0.95	8.35	0.77
0-Directional Reach (20^o)	0.25	0.44	0.03	0.43	0.77	0.06	0.36	0.67	0.05
total land-use m^2 /100m	–	–	–	5.06	2.01	0.15	–	–	–
residential m^2 /100m	–	–	–	–	–	–	-0.00	-1.57	-0.15
non-residential m^2 /100m	–	–	–	–	–	–	3.92	1.52	0.12
N=47									
R^2	0.74			0.76			0.78		
R^2 adjusted	0.73			0.74			0.75		

Note: Numbers in bold= significant difference (p<0.01); * significant difference (p < 0.05).

In conclusion, results of multivariate analyses indicate that the configuration of street networks at the scale of an individual area is a reasonably significant predictor of the variation in pedestrian movement. Although metric and directional accessibility are equally associated with the distribution of movement when all data are merged into one set, a different picture emerges when areas are analyzed separately. In Sultanahmet and in Beyazit, 0-directional reach (20o) is the primary correlate of walking. Thus, in addition to street density, the shape and alignment of streets as indexed by the direction changes needed to navigate the system, is clearly associated with pedestrian behavior. This is consistent with findings reported in section "Measuring Walkability". In Taksim, however, directional accessibility fails to correlate with pedestrian movement. In this high-density residential area, pedestrians orient their movement according to the availability of accessible streets and destinations within walking range rather than the spatial structure based on directional bias.

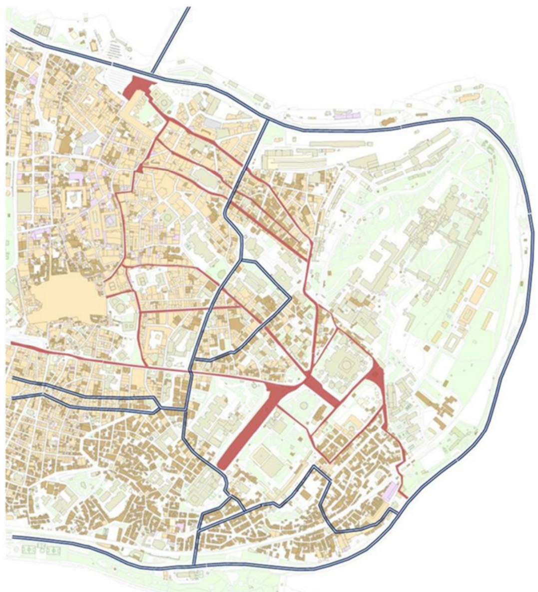
In terms of land-use density, findings indicate that at the micro-scale (analysis of individual areas) land-use variables become more significant when they are considered at the disaggregate level rather than at the aggregate level. The relative significance levels of residential building square meters are higher in comparison with non-residential land-use density. However; residential development is negatively associated with pedestrian movement, indicating the negative effect of increased number of houses within high-density commercial areas.

Applying theory to practice

One practical application of the method presented here is in developing design rules for prospective pedestrianization projects developed by local authorities. Findings of the pedestrian movement models developed in this study are used as a framework to translate the theoretical implications of these results into practice. Based on the spatial analyses and statistical models produced for the study areas, a pedestrian-oriented strategical framework was developed for Sultanahmet Square and its surroundings (Kubat et al. 2012a; Kubat et al. 2012b). The primary aim of this framework is to enhance the inter-connections between the segregated parts of the historical peninsula, and hence, to create a more extensive and integrated live center. A pedestrian connections-based framework was developed by mapping directional accessibility and land-use patterns of the area (Figure 6a). Roads with higher directional accessibility were proposed as pedestrian zones, creating a continuous, highly connected route within the historic core (Figure 6b). The pedestrian-oriented strategical framework proposed by this research takes into account the existing spatial configuration, parcel-based land-use compositions, as well as pedestrian movement distributions within the area. Thus, it encompasses an integrated and efficient scope. However, in the process of its application, these proposals need to be re-evaluated in cooperation with traffic engineers. Within the scope of this pedestrian-oriented design proposal certain strategically located spaces are studied in detail. Figure 7 shows visual proposals comparing the current conditions of these locations and projected improvements after the pedestrianization process. Pedestrian axes proposed within this framework are likely to strengthen the historic center and integrate the area with its surroundings. The new design would attract higher densities of local residents and tourists and enable pedestrians to use the area with less difficulty. As such, it is projected that the historic core would become a center of gravity for the entire district and would enhance the social and economical reputation of the entire region. These design proposals will be further tested with other aspects of urban design that are shown to influence walking in order to develop more specific recommendations about how the immediate environment of the Square needs to be redesigned.

Directional accessibility of streets captured within the area. Streets are color-coded according to 0-directional Reach (20^{o}), where red shows higher values.

a.



proposed pedestrian streets

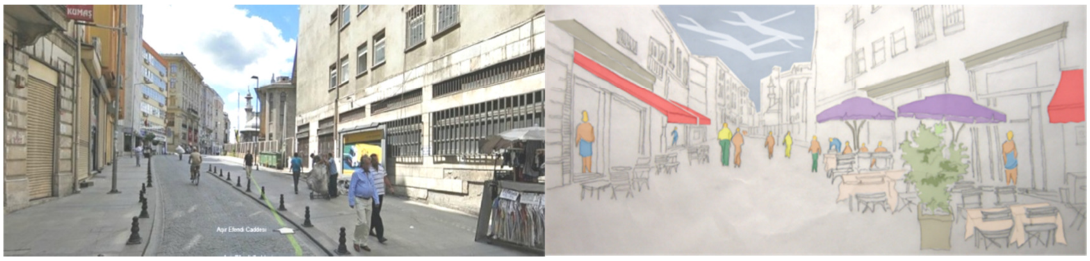
traffic zone

b

Figure 6 a) Directional accessibility model of the area overlaid on the existing street network and land-uses, and b) selected roads proposed for pedestrianization within Sultanahmet area.

a. The existing view of Ebusuud Street (southern section) and its predicted improvement after the pedestrianization process.

b. The existing view of **Ebusuud** Street (northern section) and its predicted improvement after the pedestrianization process.



c. The existing view of Aşir Efendi Street and its predicted improvement after the pedestrianization process.

Figure 7 Current conditions of selected street sections as compared with proposed improvements after the pedestrianization process.

The pedestrian-oriented strategical framework proposed here takes into account the existing spatial configuration, parcel-based land-use compositions, as well as pedestrian movement distributions within the area. Thus, it encompasses an integrated and efficient scope. However; since pedestrianization of urban spaces requires addressing multiple interacting factors, a wide range of micro-scale factors such as traffic flows, public transport, places of interests, and tourist flows will need to be further investigated before a final and more comprehensive pedestrianization strategy can be extracted.

Conclusions

The results of this study offer preliminary evidence emphasizing the importance of including street connectivity in small-scale urban design studies. Street connectivity was measured using segment-based connectivity measures, metric reach and directional reach. Based on the effect levels and significance levels of both measures, it can be concluded that increasing density of available streets and reducing direction changes within urban areas results in higher levels of pedestrians using the space. The fact that direction changes are as important as metric distance in describing street connectivity points to the role of cognitive factors. This is in accordance with research findings (Bailenson et al. 2000; Crowe et al. 2000) indicating that people orient themselves with respect to frames of reference that are as linear as possible. Results also point to the fact that navigation choices vary with the degree of familiarity with the environment. As exemplified in the cases of Sultanahmet and Beyazit, novice users are most likely to follow more direct routes with fewer direction changes (Hochmair and Frank 2002; Hölscher et al. 2006). On the other hand, pedestrians familiar with a neighborhood are likely to follow routes with shortest metric distances devoid of much cognitive effort. This is reflected in the model developed for Taksim. Therefore it would appear that in addition to street density, the manner in which streets are aligned and the direction changes needed to navigate the network facilitate pedestrian behavior.

Future Developments

The analyses presented in this study are not definitive, nor do they necessarily indicate possible causal relationship between urban form and pedestrian travel. Future work that uses longitudinal surveys in an attempt to measure pedestrian movement before and after a design move would arrive at more definitive conclusions with regard to the associations between the built environment and walking. Hence, no causality should be uncritically inferred from the statistically significant associations reported in this study.

The models developed in this study are a starting point to a more detailed and informed method of evaluating the walkability levels of urban form. A clear methodological improvement would be the consideration of other related environmental attributes linked with walking behavior. These include but are not limited to the presence of parks and recreation facilities (Pikora et al. 2002; Wendel-Vos et al. 2004), the presence of sidewalks (Handy et al. 2002; Cervero and Kockelman 1997), transit accessibility (Kitamura et al. 1997), factors related to natural features such as topography (Rodriguez and Joo 2004), and perceived aspects of the environment, such as aesthetics (Owen et al. 2004; Humpel et al. 2004). Further research that focuses on a wider range of variables would lead to more detailed and informative models capturing the association between urban form and walking. However, collecting a wide range of data across different urban areas would require a generous budget due to detailed data collection. The optimal package of environmental attributes to be included within such empirical studies is still uncertain.

By addressing the use of GIS data to develop pedestrian models, this study exemplifies a potential application of GIS methods in guiding environmental and policy initiatives to promote walking. Finer grain research, including GIS-based land-use and street network data, provide significant opportunity to develop objective measures of urban form that can inform design and planning decisions aimed at increasing overall physical activity levels. Recent studies have integrated syntactical properties of space with GIS technology to model pedestrian volumes (Raford and Ragland 2004; Ozbil et. al. 2011). A key aspect of this study is that the method for modeling pedestrian movement at the road segment scale appears to be highly applicable to Istanbul. This method may be generalized to other areas or cities. Yet limited access to rich urban form data at a smaller geographic unit of analyses (such as parcel-level land-use data) and detailed information on pedestrian movement than is generally available from regional travel surveys can become a significant barrier to directly applying this method in other studies. The presented evidence in this study may help increase emphasis on the presence of required data in guiding urban planning investment decisions. Future research will need to expand the case studies across a variety of cultural contexts to validate further or falsify the findings of this research.

In particular, this research points to the need for incorporating street connectivity measures into pedestrian movement forecasting models. Such measures may help define more clearly how connectivity encourages walking and thus supports public health. Implementation of measures of street density and measures of directional accessibility in pedestrian-oriented studies can lead to enhanced models of urban form and function, which, in return, can inform specific urban design and urban master planning decisions. We hope future work will allow planners to more accurately model relationships between urban form attributes and pedestrian travel. This understanding will be especially useful in developing strategic planning and urban design guidelines that effectively promote active forms of transportation.

Acknowledgements

The authors thank Aylin Senturk, Ece Ozden Pak, Ezgi Kucuk, Gizem Kaya, Nevset Gul Canakcioglu, Ozlem Atalay, Samira Malek, Sevcan Uclar, Yasin Baris Gogus, Fatma Belgin Gumru, Baris Kalyoncuoglu, Suveyda Bayraktar, Frederik Bechtle, Damjan Hidic, İpek Sen, Sima Vaez, Harun Ekinoglu, Deniz Agachanli, Irem Albayrak, Pelin Albayrak, Derya Bayar, Aysegul Cakmak, Sedef Çikrikci, Cisem Cildir, Ibrahim Eren, Asli Guler, Busra Karatepe in helping with the collection of pedestrian data, and Ozlem Atalay for her assistance in extracting parcel-based land-use data needed for this analysis.

REFERENCES

Bailenson, Jeremy N., Michael S. Shum, and David H. Uttal. 1998. “Road climbing: Principles governing asymmetric route choices on maps.” *Journal of Environmental Psychology* 18: 251–64.

Bailenson, Jeremy N., Michael S. Shum, and David H. Uttal. 2000. “The initial segment strategy: A heuristic for route selection.” *Memory&Cognition* 28: 306-18.

Boarnet, Marlon G., and Sharon Sarmiento. 1998. “Can land-use policy really affect travel behaviour? A study of the link between non-work travel and land-use characteristics.” *Urban Studies* 35: 1155-169.

Cervero, Robert, and Carolyn Radisch. 1995. “Travel choices in pedestrian versus automobile oriented neighborhoods.” *Transport Policy* 3: 127-41.

Cervero, Robert, and Kara Kockelman. 1997. “Travel demand and the 3Ds: density, diversity, and design.” *Transportation Research D: Transport and Environment* 2:199-219.

Cervero, Robert. 2002. “Built environments and mode choice: toward a normative framework.” *Transportation Research Part D: Transport and Environment* 7: 265-84.

Conroy-Dalton, Ruth. 2003. “The secret is to follow your nose, route path selection and angularity.” *Environment and Behavior* 35(1): 107-31.

Crowe, David A., Bruno B. Averbeck, Matthew V. Chafee, John H. Anderson, and Apostolos P. Georgopoulos. 2000. “Mental maze solving.” *Journal of Cognitive Neuroscience* 12: 813-27.

Ewing, Robert H. 1996. *Best development practices: doing the right thing and making money at the same time*. Chicago, IL: American Planning Association.

Frank, Lawrence D., and Gary Pivo. 1994. “Relationships between land use and travel behavior in the Puget Sound Region.” *Final Summary Report prepared for the Washington State Transportation Commission.*

Frank, Lawrence D. 2000. “Land use and transportation interaction: Implications on public health and quality of life.” *Journal of Planning Education and Research* 20: 6–22.

Goldberg, David, Barbara McCann, Lawrence D. Frank, Jim Chapman, and Sarah Kavage. 2007. "New Data for a New Era: A Summary of the SMARTRAQ Findings; Linking Land Use, Transportation, Air Quality and Health in the Atlanta Region." *SMARTRAQ Summary Report SmartTraq and Smart Growth*.

Handy, Susan L. 1996. "Urban form and pedestrian choices: a study of Austin neighborhoods." *Transportation Research Record* 1552:135-44.

Handy, Susan L., Marlon G. Boarnet, Reid Ewing, and Richard E. Killingsworth. 2002. "How the built environment affects physical activity. Views from urban planning." *American Journal of Preventive Medicine* 23: 64–73.

Hess, Paul M., Anne V. Moudon, Mary C. Snyder, and Kiril Stanilov. 1999. "Site design and pedestrian travel." *Transportation Research Record* 1674: 9-19.

Handy, Susan. 2005. *Critical assessment of the literature on the relationships among transportation, land use, and physical activity.* Washington, DC: Transportation Research Board and the Institute of Medicine Committee on Physical Activity, Health, Transportation, and Land Use.

Hillier, Bill. 1996. *Space is the machine: a configurational theory of architecture*, Cambridge University Press.

Hillier, Bill, and Shinichi Iida. 2005. "Network effects and psychological effects: a theory of urban movement." In *5th International Symposium on Space Syntax,* edited by Ness AV. Delft: Teche Press.

Hochmair, Hartwig, and Andrew U. Frank. 2002. "Influence of estimation errors on wayfinding-decisions in unknown street networks-analyzing the least-angle strategy." *Spatial Cognition and Computation* 2:283–313.

Hölscher, Christoph, Tobias Meilinger, Georg Vrachliotis, Martin Brösamle, and Markus Knauff. 2006. "Up the Down Staircase: Wayfinding Strategies and Multi-Level Buildings." *Journal of Environmental Psychology* 26: 284-99.

Humpel, Nancy, Neville Owen, Eva Leslie, Alison L. Marshall, Adrian E. Bauman, and James F. Sallis. 2004. "Associations of location and perceived environmental attributes with walking in neighborhoods." *American Journal of Health Promotion* 18: 239–42.

Jansen-Osmann, Petra, and Gunnar Wiedenbauer. 2004. "The influence of turns on distance cognition: New experimental approaches to clarify the route-angularity effect." *Environment and Behavior* 36: 790-813.

JHK and Associates. 1987. *Development Related Ridership Survey I.* Washington, D.C.: Washington Metropolitan Area Transit Authority.

Kitamura, Ryuichi, Patricia L. Mokhtarain, and Laura Laidet. 1997. "A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay area." *Transportation* 24: 125–28.

Krizek, Kevin J. 2003. "Residential relocation and changes in urban travel: Does neighborhood-scale urban form matter?" *Journal of the American Planning Association* 69: 265-81.

Kubat, A. Sema, Ayse Özbil, Özlem Özer, and Harun Ekinoğlu. 2012a. "The Effect of Built Space on Wayfinding in Urban Environments: A Study of the Historical Peninsula in Istanbul." Paper presented at the 8th International Space Syntax Symposium, Santiago, Chili, January 3-6.

Kubat, A. Sema, Ayse Özbil, and Özlem Özer. 2012b. "Urban Design analyses on Movement and Perception of Sultanahmet Square, İstanbul." Istanbul Metropolitan Municipality, Directorate of Strategical Planning, Projem İstanbul.

Marshall, Norm, and Brian Grady. 2005. "Travel demand modeling for regional visioning and scenario analysis." *Transportation Research Record: Journal of the Transportation Research Board* 1921: 44-52.

Mately, Ted M., Lois M. Goldman, and Brian J. Fineman. 2001. "Pedestrian travel potential in northern New Jersey." *Transportation Research Record* 1705: 1-8.

Moeser, Shannon D. 1998. "Cognitive mapping in a complex building." *Environment and Behavior* 20: 3–20.

Montello, Daniel R. 1991. "Spatial orientation and the angularity of urban routes: A field study." *Environment and Behavior* 23: 47-69.

Mossberger, Karen, Susan E. Clarke, and Peter John. 2012. "Studying Politcs in an Urban World: Research Traditions and New Directions." In *The Oxford Handbook of Urban Politics*, edited by Karen Mossberger et al. Oxford University Press, 3-29.

Oakes, J. Michael, Ann Forsyth, and Kathyrn H. Schmitz. 2007. "The effects of neighborhood density and street connectivity on walking behavior: the Twin Cities walking study." *Epidemiologic Perspectives and Innovations*: 4-16.

Owen, Neville, Nancy Humpel, Eva Leslie, Adrian Bauman, and James F. Sallis. 2004. "Understanding environmental influences on walking: review and research agenda." *American Journal of Preventive Medicine* 27: 67–76.

Ozbil, Ayse, John Peponis, and Brian Stone. 2011. "Understanding the link between street connectivity, land use and pedestrian flows." *Urban Design International* 16: 125-41.

Parsons Brinkerhoff Quade and Douglas Inc., and Cambridge Systematics & Calthorpe Associates. 1993. *Making the Land Use, Transportation, Air Quality Connection (LUTRAQ).* Portland, OR: 1000 Friends of Oregon.

Peponis, John, and Jean Wineman. 2002. "Spatial structure of environment and behavior." In *Handbook of environmental psychology,* edited by R. Bechtel et al. New York: John Wiley and Sons, 271-292.

Peponis, John, Sonit Bafna, and Zongyu Zhang. 2008. "The connectivity of streets: reach and directional distance." *Environment and Planning B: Planning and Design*35 : 881-901.

Pikora, Terri J., Fiona C. L. Bull, Konrad Jamrozik, Matthew Knuiman, Billie Giles-Corti, and Rob J. Donovan. 2002. "Developing a reliable audit instrument to measure the physical environment for physical activity." *American Journal of Preventive Medicine* 23: 187–94.

Raford, Noah, and David Ragland. 2004. "Space Syntax Innovative Pedestrian Volume Modeling Tool for Pedestrian Safety." *Transportation Research Record: Journal of the Transportation Research Board* 1878: 66-74.

Reilly, M. Kathleen. 2002. "Influence of urban form and land use on mode choice: evidence from the 1996 Bay area travel survey." Paper Presented at the 81st annual meeting of the TRB, Washington, DC.

Rodriguez, Daniel A., and Joonwon Joo. 2004. "The relationship between non-motorized mode choice and the local physical environment." *Transportation Research Part D* 9: 151–73.

Rodriguez, Daniel A., Semra Aytur, Ann Forsyth, J. Michael Oakes, and Kelly J. Clifton. 2008. "Relation of modifiable neighborhood attributes to walking." *Preventive Medicine* 47: 260-64.

Sadalla, Edward K., and Stephen G. Magel. 1980. "The perception of traversed distance." *Environment and Behavior* 12: 65-79.

Saelens, Brian E., James F. Sallis, and Lawrence D. Frank. 2003. "Environmental correlates of walking and cycling: findings from the transportation, urban design, and planning literatures." *Annals of Behavioral Medicine* 25: 80-91.

Song, Yan. 2003. *Impacts of urban growth management on urban form: a comparative study of Portland, Oregon, Orange County, Florida and Montgomery County, Maryland.* National Center for Smart Growth Research and Education, University of Maryland.

"The Results of Address Based Population Registration System, 2012". *The Turkish Statistical Institute*, accessed 28 January, 2013.

Wendel-Vos, G. C. Wanda, A. Jantine Schuit, Raymond De Niet, Hendriek C. Boshuizen, Wim H.M. Saris, and Daan Kromhout. 2004. "Factors of the physical environment associated with walking and bicycling." *Medicine and Science in Sports and Exercise* 36:725–30.