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Modeling walkability: The effects of street design, street-network configuration and land-use on pedestrian movement

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Abstract

This study explores the relative association of street design –local qualities of street environment–, street network configuration –spatial structure of the urban grid–, and land use patterns with the distribution of pedestrian flows. The aim is to better understand the extent to which systematically measured street-level urban design qualities and objectively measured street network configuration are related to pedestrian movement, controlling for land use.

20 2kmx2km areas in Istanbul were studied in order to establish correlations between street design, street configuration and densities of pedestrian movement. Pedestrian data were collected on selected road segments within the areas. Same road segments were characterized through detailed field-surveys in terms of aesthetic qualities, signage, sidewalk design, pedestrian crossings/traffic lights, ground floor uses as well as GIS-based hosing plot-level (parcel-level) land use density and street-level topography. Street network configurations within the areas were evaluated using angular segment analysis (Integration and Choice) as well as two segment-based connectivity measures (Metric and Directional Reach). Linear models were developed to investigate the relationships among street design, street network configuration, land use, and walking behavior.

This study contributes to the literature by offering insights into the comparative roles of urban design qualities of the street environment and street network layout on pedestrian movement. Preliminary findings imply that notwithstanding the significance of certain aspects of the street environment that relate to local urban design qualities, the overall spatial configuration of street network may prove to be a significant variable for the description and modulation of pedestrian movement.

Keywords
Istanbul, Land use, Pedestrian movement, Street design, Street network configuration .

1. Introduction

Creating walkable urban environments have implications for public health and environmental welfare as well as urban sustainability (US Department of Health and Human Services, 1996), but intervention strategies need to be built through empirical research that identifies correlates of walking behavior (Sallis, Owen, & Fotheringham, 2000). While socio-demographic (i.e. ethnicity, income, age) correlates of walking have been widely probed in the literature (Sallis et al., 2000; Timperio et al., 2006), physical environmental variables have been studied with much less rigor. However; the limited number of studies on the link between the built environment and physical activity demonstrate that physical environmental variables are significantly associated with walking behavior controlling for socio-demographic factors (Giles-Corti & Donovan, 2002).

1.1. Street design, urban form and pedestrian movement

Researches in health and urban design investigating the environmental correlates of walking have sufficiently documented associations between street-level design and pedestrian activity. The majority of emphasis is placed on the qualities of urban design, treated with reference to the immediate condition of individual streets. The local correlates of the street environment used in empirical studies range from the dimensions and design of sidewalks to the frontages of retail or the prevailing levels of environmental comfort that may encourage pedestrian movement (Badland & Schofield, 2005; R. Ewing, Brownson, & Berrigan, 2006; R. Ewing & Handy, 2009; Gehl, Kaefer, & Reigstad, 2006). Pedestrian safety, of course, is also shown to be a major factor in determining physical activity levels (Boarnet, Anderson, Day, McMillan, & Alfonzo, 2005). Safe and pleasant conditions encourage walking (Brown, Werner, Amburgey, & Szalay, 2007; C. Brown, Jones, & Braithwaite, 2007). The presence of street crossings, attractive landscaping, tree covers, and signalization (Agrawal, Schlossberg, & Irvin, 2008; Cao, Mokhtarian, & Handy, 2007), as well as aesthetic or safety features, such as cleanliness, interesting sights, and architecture (Appleyard, 1982; Gehl, 2011), have been shown to encourage walking in adults and children. In a literature review study in the health and behavioral sciences, Humpel, Owen, and Leslie (2002) concluded that accessibility to recreational facilities, opportunities for physical activity, and aesthetic attributes were consistently and significantly related to physical activity, while weather and safety attributes were less consistently associated with the behavior.

Evaluating such local urban design attributes is clearly important in creating environments supportive of walking. However; walking is a context-dependent activity that requires navigating *through* spaces, not *in* spaces. Thus, it cannot be fully explained based on the local qualities of the individual street isolated from its surroundings. Any type of walking (exploratory or directed) requires pedestrians to explore perceptually available connections or exploit available connections that have been cognitively registered.

Researchers in transportation and planning, on the other hand, have focused on urban form aspects of walkability, characterized in terms of proximity (distance) and connectivity (directness of traveled route) (Frank, 2000), to uncover their associations with pedestrian movement. 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 & 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 & Pivo, 1994; Marshall & 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; Rodri guez & Joo, 2004) while having destinations within walking distance from origins (homes, stations, schools, etc.) increases the odds of walking (Frank & Engleke, 2000; Handy & Clifton, 2001).

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, Sallis, & Frank, 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 & Kockelman, 1997), block size (Hess, Paul M.; Muodon, Anne V.; Snyder, Mary C.; Stanilov, 1999; Song, 2003), intersection density (Cervero & Radisch, 1995; Reilly & Landis, 2002), percent four way intersections (M. Boarnet & Sarmiento, 1998; Cervero & Kockelman, 1997), street density (S. Handy, 1996; Matley, Goldman, & Fineman, 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 (Greenwald & Boarnet, 2001; S. L. Handy, 1992; Rajamani, Handy, Knaap & Song, 2003; Shriver, 1997). However; the foregoing findings 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).

1.2. Spatial configuration and pedestrian movement

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, Forsyth, & Schmitz, 2007; Rodríguez, Aytur, Forsyth, Oakes, & Clifton, 2008). One reason is the absence of measures that can systematically characterize the spatial structures of urban street networks at various scales and hierarchies. The significance of spatial structure in affecting pedestrian movement has been addressed through the framework of configurational analysis of space syntax. The methodology of space syntax 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, Shum, & Uttal, 2000; Crowe, Averbeck, Chafee, Anderson, & Georgopoulos, 2000; B. Hillier & Iida, 2005; Jansen-Osmann, P.; Wiedenbauer, 2004; Montello, 1991; Sadalla & Magel, 1980). Earlier studies have shown that road segments that are accessible from their surroundings with fewer direction changes tend to attract higher flows (Hillier, Penn, Hanson, Grajewski, & Xu, 1993; Peponis, Ross, & Rashid, 1997). Recent research has demonstrated street network design to be significantly related to recreational (Lee & Moudon, 2006) as well as transportation walking behaviors (Ozbil & Peponis, 2012). Since walking occurs according to the fine grain of environment as well as according to its larger scale structure, appropriately discriminating measures of street connectivity are critical for designing for walkability.

This study contributes to the literature by offering insights into the comparative roles of street design –local qualities of street environment–, street network configuration –spatial structure of the urban grid–, and land use patterns with the distribution of pedestrian flows. The aim is to better understand the extent to which systematically measured street-level urban design qualities and objectively measured street network configuration are related to pedestrian movement, controlling for land use.

1.3. The case of Anatolian part of Istanbul

The study areas are drawn from diverse neighborhoods that vary substantially in walkability (street connectivity patterns), as well as their locations within the city (Figure 1). Kadıköy and Üsküdar are central-city districts, which include some of the most densely walked street segments within the city. Ataşehir, which became a district in 2008, is a contemporary in-town environment with high-end residential gated-communities and office skyscrapers while Ümraniye and Kartal are peripheral districts. The underlying reason for studying the Anatolian part is due to the different urban patterns dominating each continent. The European part is mostly dominated by high-rise mass housing, service and commercial land uses, whereas the Anatolian part reflects mostly a residential character with mixed land uses prevailing the central parts. Although the selected areas represent a small cross-section of the entire city, the sum of their population equals to one-sixth of Istanbul’s total population.

Table 1 presents a quantitative profile of the selected areas in terms of street patterns, population density, movement densities and land use compositions summarized based on their districts. This preliminary benchmarking demonstrates notable differences between areas. The population densities of the areas, calculated on the basis of the census blocks associated with the street segments for which pedestrian counts were taken, range from 145 to 290 per hectare with Üsküdar,

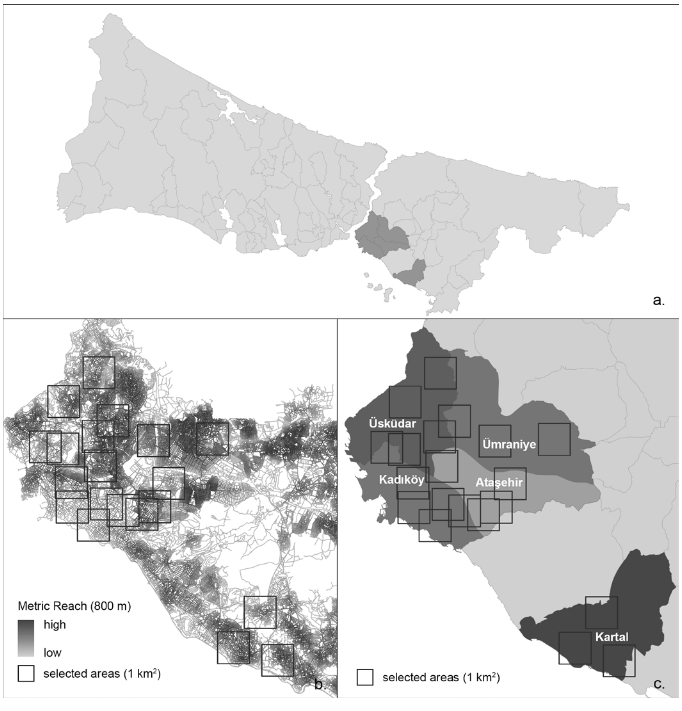


Figure 1. *Locations of (a) selected districts and surveyed areas. Maps are colored based on (b) Metric Reach (800m), and (c) boundaries of the selected districts.*

Ataşehir and Kadıköy having similar densities. The mean density of moving pedestrians per 100m is 38, 29, 24, 24, and 19 for Ümraniye, Kartal, Ataşehir, Kadıköy, and Üsküdar respectively. The areas summarized in terms of their districts also differ significantly in their average street density. Average metric reach, from high to low, is consistently in descending order from Ümraniye to Üsküdar, Ataşehir, Kadıköy and Kartal for 2km radii. However, Kadıköy has the highest two-directional reach, whereas Üsküdar and Kartal have similar lower averages. The magnitude of land use densities follows the same or-

Table 1. *Urban form characteristics of selected areas summarized in terms of their districts.*

	Ataşehir	Kadıköy	Kartal	Ümraniye	Üsküdar
Numbers of selected areas and audited segments					
Number of 2kmx2km areas selected	4	6	3	3	4
Number of segments audited	158	238	120	116	158
Densities of residential population and pedestrians					
Average population density per hectares	202	201	170	145	209
Average number of pedestrians per 100m	23.98	23.87	29.16	37.59	18.66
Characteristics of street network configuration					
Average Metric Reach (1600 m)	61.45	54.83	54.71	77.49	62.39
Average 2-Directional Reach (20º)	5.07	8.08	4.14	5.93	3.25
Average global Integration (n)	6373	6162	5309	6644	5919
Average global Choice (n) (in millions)	331	346	225	603	183
Land use characteristics (in thousands)					
Average total residential sq mt	857	855	706	999	836
Average total non-residential sq mt	188	167	240	238	46
Average total sq mt	1046	1022	946	1237	882
mixed-use entropy index	0.38	0.37	0.57	0.44	0.19

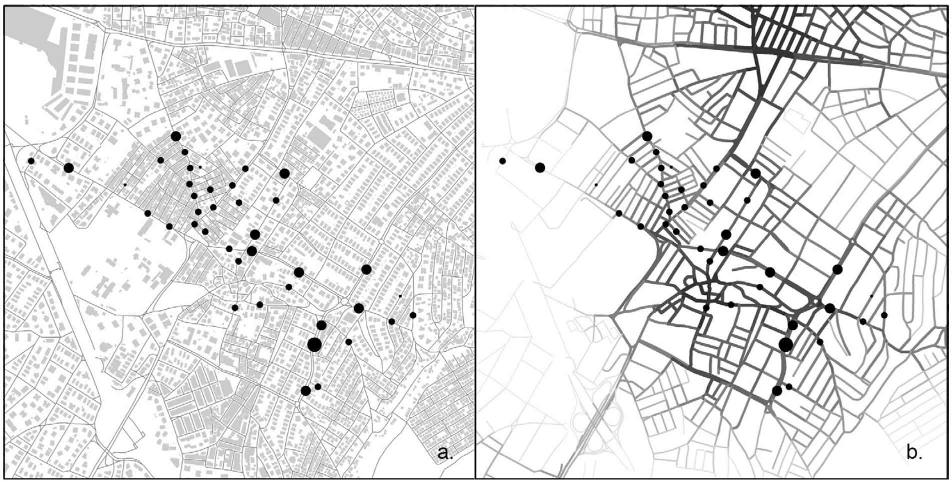


Figure 2. *(a) Graphic representation of observed pedestrian densities through circles of differing diameters denoting the differing densities of observed movements. (b) Location of pedestrian observations on the configurational map showing metric/directional accessibility according to Metric Reach (1600mt). Dark-to-light lines denote higher-to-lower metric accessibility within the overall Anatolian part of the city.*

der as that of street density. Ümraniye and Kartal have the highest land use intensifications while Üsküdar has the lowest total land use density. Non-residential land use density is highest in Kartal and Ümraniye, which also have relatively higher mixed-use entropy indices, and lowest in Üsküdar, which is primarily a residential district. In terms of residential building square meter, Ümraniye has the highest density while Kadıköy, Ataşehir and Üsküdar are found to have similar densities for the 2-kilometer buffer range with Kartal having the lowest density.

Overall, the initial tabulation suggests a strong correspondence between the average volume of pedestrian movement and the average density of streets and land development. As higher development densities are located in areas with denser street networks, it seems plausible that the association between pedestrian density and street density is a by-product of land use. In the next section, however, the examination of the data at street segment level suggests that street connectivity has a strong role in determining the distribution of pedestrian density across and within areas.

2. Methodology

This study was conducted in 5 consecutive stages. In the first stage, data on actual pedestrian volumes were recorded by conducting on-site observations in the selected areas. In the second stage, detailed field surveys were conducted to assess the degree of street-level accessibility and pedestrian quality. In the third stage, GIS-based plot-level land use compositions were measured at the street-segment scale. In the fourth stage, street network configuration of the Anatolian part of Istanbul was evaluated using various topo-geometric configurational measures. In the last stage, the associations between distribution of pedestrian movement, street design qualities, street-level land use compositions, and street network configuration were studied using linear statistical analyses.

2.1. Pedestrian observations

Due to resource limitations, only 40 street segments within each 2kmx-2km study area were audited. The selection of audited street segments were based on two criteria: (1) not a dead-end street, (2) representative of a wide range of configurational qualities of the street network. These sampling criteria

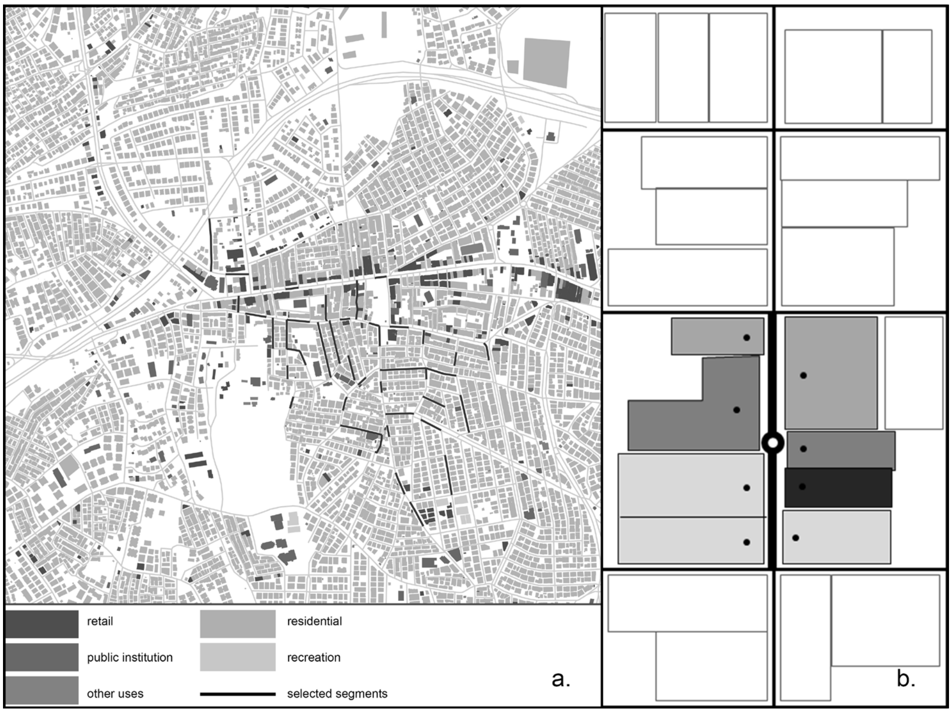


Figure 3. *(a) Land use compositions within a selected 2x2km urban area, and (b) gross densities of buildings that have their access on the individual road segment associated with each segment along the path.*

ensured consistency among the sampled segments in terms of the overall pedestrian facilities. Based on these criteria, audited-segments were selected to include street-segments with differing structural levels (Figure 2).

2.2. Field surveys

Street segments were characterized through detailed field surveys in terms of the pedestrian quality attributes that are shown to affect navigation in urban environments through their impacts on pedestrians' perceptions. These include accessibility –sidewalk width (average width on both sides) and maintenance; street sign (presence of street name on audited segment); safety (number of pedestrian crossings and traffic-signals on audited segments relativized by street length; average width of buffer between the sidewalk and the streets on both sides as well as posted speed limit on the audited segment); aesthetics –enclosure along sidewalks (average building setback from the sidewalk) and street trees (presence of trees on either side of the audited segment); street-front land uses (number of residential and non-residential land uses opening directly on each individual street segment relativized by street length); as well as street level topography (average degree of slope along the audited street segment). Since this study is quantitative in nature, soft-architectural-parameters, such as smell, noise and light, which are harder to quantify were not considered in the field surveys.

Hence, a total number of 800 street segments were audited, and the average length of audited segments was 88.87 meters. Street segments whose total length was <%10 of average total audited segment length were excluded from the dataset (n=10). The remaining 790 segments were included in the analysis.

2.3. Land use compositions

Land use data were acquired from the 2014 GIS-based land use data provided by the Istanbul Metropolitan Municipality. Plot-based data were categorized into residential (single family and multi-family housing) 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 density was calculated as a linear measure at the street segment scale by computing residential and non-residential building square meter associated with each individual street segment, and relativized by segment length: square meter of development per 100m of street length. Figure 3 illustrates land use compositions within a study area and demonstrates the way in which land use density was measured at the segment scale.

2.4. Configurational analyses

Street network configuration of selected areas was evaluated using angular segment analysis (Integration and Choice) implemented in Depthmap10 (Turner and Friedrich, 2010-2011), as well as two parametric connectivity measures (Metric and Directional Reach) implemented in GIS. The decision to include different measures is motivated by the variety of configurational qualities (metric, geometric and topological) captured by each measure. *Segment Angular Integration* measures how accessible each space from all the others within the radius using the least angle measure of distance. *Segment*

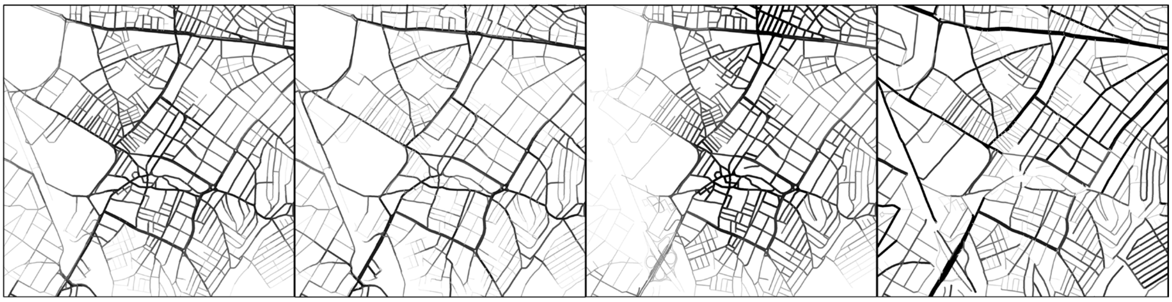

a. Integration (800m) b. Choice (800m) c. Metric Reach (800m) d. 2-Directional Reach (20^o)

Figure 4. *Representing a study area (2kmx2km) with different configurational measures.*

Angular Choice which measures how many times a space is selected on journeys between all pairs of origins and destinations (Hillier & Iida, 2005). In other words, integration measures how easy it is to access one space (road segment) from all others in the network; whereas Choice measures how likely it is for a space to be selected moving from one space to another in the network (Hillier & Iida, 2005). These two measures represent the *to* and *through* movement potentials of the street segments (Hillier, Yang, & Turner, 2012). Choice and Integration at radii 400-, 800-, and 1600-meter were calculated.

Street network configuration of the entire region was evaluated by using two parametric segment-based measures of connectivity (Peponis, Bafna, & Zhang, 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. Metric Reach was computed for 1600-, 800- and 400-meter walking distance thresholds. Directional Reach was computed for two direction changes subject to a 20° angle threshold. The 20° angle threshold was selected to set the threshold low enough to make the analysis sensitive to street sinuosity. Computing directional reach for two direction changes provides an estimate of how well a street segment is embedded in its surroundings from the point of view of directional distance. In other words, it takes high values as streets become more linearly extended and as intersections to other linearly extended streets become denser. Figure 4 illustrates Integration and Choice at a radius of 800 meters, Metric Reach (800m), and 2-directional Reach (20°) respectively.

2.5. Statistical analyses

Multivariate regression analyses were conducted to examine the associations between street-level urban design features, land use characteristics, and street-network configuration in explaining the distribution of pedestrian densities. The analyses were conducted in two stages. In the first stage, density of pedestrian flows was modeled for all areas considered as a single set. Street design measures were entered into the regression first to allow for the evaluation of these variables in context relative to other factors affecting pedestrian behavior. Configurational measures and land use variables were then added into the model respectively to demonstrate the effect of adding each to the model and to identify the comparative effect and significance levels of each measure. In the second stage of analyses, separate multivariate regression models were estimated for the distribution of movement densities within the individual areas summarized according to their districts. Since configurational measures computed for 800 meter radius produced higher coefficients in the analyses, these measures are reported in the following tables. Logarithmic transformation was applied to the dependent variable (pedestrian density relativized by 100m) as its distribution indicated some degree of skewness.

3. Results

3.1. Regression analyses for all areas considered as a single set

Table 2 summarizes the results of regression models for 3 sets of models estimating the distribution of pedestrian densities for all areas considered as a single set. For street design measures, the most significant correlate of movement density is average sidewalk width. In fact the impact of average sidewalk width along road segments on the distribution of movement is quite consistent even when configurational and land use variables are added. The results indicate that movement densities increase with increased sidewalk width and sidewalk maintenance along the segments. Surprisingly, the signs of speed limit and the presence of street trees are positive and negative respectively, which is contrary to a priori expectations and earlier results. This may be due to the fact that there is not enough variability among the selected areas in terms of street speed limits (min. 10km/hour; max. 45 km/hour) and tree aligned streets. Average road segment slope is negatively and significantly associated with movement densities. Indeed the impact of street-level gradient on the distribution of movement is quite consistent across models suggesting that increased wavy topography hinders the willingness to walk.

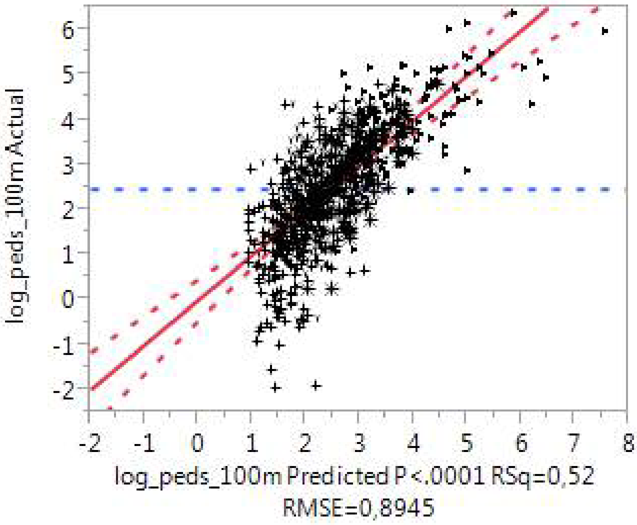


Figure 5. *Scatter plot showing the natural log of pedestrian movement densities by the multivariate regression model.*

The inclusion of configurational measures, Choice and Integration at radius 800 meters as well as Metric Reach (800m) and 2-Directional Reach (20º), adds a considerable increase of 14% ($p<0.001$) to the explanatory power of the model. All street network measures are positive and statistically significant at the 99% level with similar standardized coefficients. However; with the addition of land use measures the overall model, there is a slight decrease in the significance levels of Integration and Choice while the standardized coefficients and significance levels of Metric and Directional Reach remain consistent. Hence; it can be concluded that the distribution of pedestrian movement is more strongly associated with metric and directional accessibility of road segments as compared to the *to-* and *through*-movement potentiality of the street.

Associations between land use

Table 2. *Effect tests for multivariate regressions estimating the proportion of walking for all areas considered as a single set.*

	street design measures			**+ configurational**			**+ land use measures**		
	β	t	Std β	β	t	Std β	β	t	Std β
		2.31*			0.12			1.18	
avg. slope	*-0.05*	*-1.67*	*-0.05*	**-0.11**	**-3.90**	**-0.11**	-	-2.99*	-0.08*
setback distance	-0.00	-0.94	-0.03	0.00	0.82	0.03	*0.00*	*1.94*	*0.06*
avg. sidewalk width	**0.00**	**9.30**	**0.35**	**0.00**	**7.80**	**0.28**	**0.00**	**5.12**	**0.17**
avg. buffer width	*-0.00*	*-1.89*	*-0.06*	-0.00	-1.44	-0.04	-0.00	-0.75	-0.02
sidewalk maintenance	0.21*	2.02*	0.07*	0.25*	2.62*	0.08*	0.14	1.59	0.05
street trees [no]	0.12*	2.55*	0.09*	0.02	0.38	0.01	-0.01	-0.19	-0.01
crosswalk existence [no]	0.15	0.40	0.05	0.23	0.69	0.07	0.19	0.63	0.06
traffic signal existence [no]	-0.44	-1.16	-0.10	-0.33	-0.96	-0.08	-0.38	-1.23	-0.09
street names [no]	0.04	0.86	0.03	0.02	0.58	0.02	0.02	0.58	0.01
speed limit	**0.03**	**4.81**	**0.18**	*0.01*	*1.94*	*0.07*	0.00	0.05	0.00
Integration (800m)				**0.00**	**3.13**	**0.16**	0.00*	2.59*	0.12*
Choice (800m)				**0.00**	**4.05**	**0.16**	0.00*	2.51*	0.09*
Metric Reach (800m)				**0.05**	**3.90**	**0.16**	**0.05**	**3.93**	**0.15**
2-Directional Reach (20º)				**0.02**	**4.40**	**0.14**	**0.02**	**3.95**	**0.12**
#residential land use							**-0.03**	**-3.97**	**-0.11**
#non-residential land use (100m)							**0.06**	**12.64**	**0.38**
residential land use density (100m)							0.00	1.13	0.03
non-residential land use density							0.00*	2.02*	0.05*
N: 790									
R^2		**0.26**			**0.40**			**0.52**	
R^2 adjusted		**0.24**			**0.39**			**0.51**	

Bold: $p<0.001$; *: $p<0.05$; italic: $p<0.1$

measures and pedestrian flows are statistically significant for the objective GIS-based measures of residential and non-residential land uses (both the number of frontages and the gross densities) at the road segment scale. The most significant predictor of movement densities is the number of non-residential uses having direct access from the road segments. The results indicate that movement densities are significantly associated with both increased number of active uses and increased non-residential land use density as well as with decreased number of residential uses along road segments across areas. This suggests that increasing non-residential activities both at the ground floor level and the road segment scale and reducing residential uses would significantly increase pedestrian movement densities. Figure 5 illustrates the scatter plot showing the natural log of pedestrian densities as affected by variables in the multivariate regression model and Figure 6 shows the prediction equations for each variable in the model.

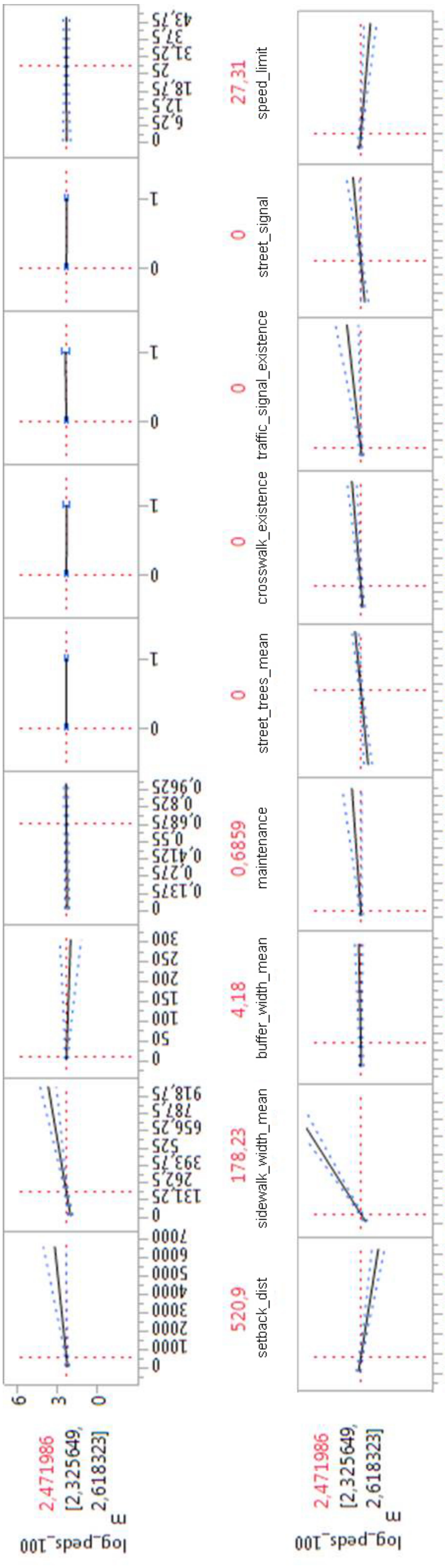


Figure 6. *Prediction equations for the variables in the multivariate regression model.*

Finally, street-level urban design quality attributes, configurational measures and land uses were entered together into a stepwise regression based on the forward selection method to compare each variable's individual contribution and to identify the significant variables in explaining the distribution of pedestrian flows (Table 3). The results are similar with the previous multivariate regression models. The number of non-residential land uses associated with road segments (positive) entered the model as the most significant predictor. In fact, active frontages on the ground floor at the road segment scale alone explain 35% of the variation in movement densities. From street network configuration measures Integration within 800 meters is the most significant variable. This indicates that *to*-movement within urban areas is positively associated with the choice to walk. 2-Directional Reach (20°), Metric Reach (800m) and Choice at a radius of 800 meters also entered the model as significant variables along with the number of residential uses, average slope, non-residential density, setback distance, and sidewalk maintenance, but with much less contribution to the overall model. While adding Integration and av-

Table 3. *Parameter estimates for the stepwise regression model estimating the distribution of movement densities for all areas considered as a single set.*

	R^2	β	AIC	p value
#non-residential uses (100m)	0.35	0.07	2288.61	0.00
Integration (800m)	0.41	0.00	2213.3	0.02
avg. sidewalk width	0.46	0.00	2140.23	0.00
#residential uses (100m)	0.48	-0.03	2121.08	0.00
2-Directional Reach (20°)	0.49	0.02	2111.41	0.00
Metric Reach (800m)	0.50	0.05	2098.94	0.00
avg. slope	0.50	-0.08	2091.14	0.00
Choice (800m)	0.51	0.00	2086.12	0.01
non-residential density (100m)	0.51	0.00	2082.25	0.02
setback distance	0.51	0.00	2079.56	0.03
sidewalk maintenance	0.51	0.00	2078.85	0.08
residential density	0.52	0.00	2079.55	0.14
traffic signal existence [no]	0.52	0.00	2082.00	0.40
avg. buffer width	0.52	0.00	2083.50	0.83
street names [no]	0.52	0.00	2085.24	0.64
crosswalk existence	0.52	0.00	2089.04	0.62
street trees [no]	0.52	0.00	2091.11	0.31
speed limit	0.52	0.00	2093.23	0.58
N		790		

erage sidewalk width to the model results in a consequential increase in the predictive power of the model (R^2 change=7-6%; p<0.001), the inclusion of the latter variables adds a modest increase of 2-1% (p<0.001) respectively. From street design variables average sidewalk width is the strongest correlate of pedestrian flows, suggesting that increasing sidewalk width along segments encourages pedestrians to walk. The signs of street design quality attributes are consistent with a priori expectations; for example, pedestrian flows increase with increased average sidewalk width, higher sidewalk maintenance, and reduced slope.

3.2. Regression analyses for individual areas summarized within their districts

In order to better understand the distribution of pedestrians in each area, multivariate regression models were estimated by considering individual areas grouped according to their districts separately. Tables 4-8 illustrate the results of regression models estimating the distribution of pedestrian densities for individual areas summarized in terms of their districts.

The results suggest that the primary factors in explaining the distribution of pedestrian movement are the number of non-residential land uses at the road segment scale along with two configurational measures, Metric and 2-Directional Reach. Consistent with theory, in the analyses of individual districts movement densities are strongly associated with the number of active uses correlated with the ground floor design. The results suggest that the impact of non-residential land use on the distribution of movement is quite consistent across models. The positive coefficients of the number of non-residential uses opening directly onto the street segment suggest that movement levels increase with higher active frontages. No other significant associations are observed for other land use measures, except for Kadıköy. In Kadıköy, which is dominated by residential uses with non-residential land uses occupying the ground floors, movement densities are also sensitive to increased non-residential building square meter at the road segment scale as well as reduced number of residential uses on the ground floors.

Consistent with results reporting analyses for all areas considered as a single set, results demonstrate that movement densities are strongly associated with Metric Reach (800m) and 2-Directional Reach (20°). In fact, in Ataşehir and Kartal, effect levels and significance levels indicate that Metric Reach is the main factor associated with the distribution of movement. The coefficient for the configurational variable is positive and statistically significant (at a 99 per cent level of confidence). The relationship between the distribution of pedestrian movement and directional accessibility is more pronounced in Kadıköy, which includes street segments linked more directly to their surroundings, than Kartal whose street network texture is dominated by a warped pattern. By contrast, Integration and Choice at a radius of 800 meters only appear to be statistically significant for two areas (Üsküdar and Ümraniye respectively) at a 95% confidence level. This implies that pedestrian movement at the road segment scale is significantly shaped by the potentiality of a street for metric and directional accessibility rather than both for *through*- and *to*-movement.

The evidence relating street design factors to walking is stronger for some of the measures. Average sidewalk width is positively and significantly associated with pedestrian flows across all models (except for Kadıköy, which has more or less a uniform standard of sidewalk width), while average road segment slope is negatively and significantly associated with movement for all areas (except for Kadıköy and Ümraniye, which have relatively smooth terrain). On the other hand, no other consistent associations are found for the rest of the street design variables.

Table 4. *Parameter estimates for the multivariate regression model estimating the distribution of movement densities for Kadıköy.*

	β	t	std β
avg. slope	0.04	0.49	0.03
setback distance	0.00*	2.26*	0.12*
avg. sidewalk width	0.00	1.17	0.09
avg. buffer width	0.00	0.11	0.01
sidewalk maintenance	0.17	0.89	0.05
street trees [no]	-0.02	-0.30	-0.02
crosswalk existence [no]	-0.13*	-2.01*	-0.10*
traffic signal existence [no]	-0.11	-1.36	-0.07
street names [no]	0.02	0.42	0.02
speed limit	0.01	0.79	0.05
Integration (800m)	0.00	0.40	0.03
Choice (800m)	0.00	1.04	0.07
Metric Reach (800m)	0.03	1.10	0.08
2-Directional Reach (20°)	**0.02**	**3.75**	**0.20**
#residential land use (100m)	-0.05*	-3.21*	-0.19*
#non-residential land use (100m)	**0.06**	**8.38**	**0.49**
residential land use density (100m)	0.00	0.56	0.04
non-residential land use density (100m)	0.00*	2.09*	0.11*
N: 238			
R^2		**0.57**	
R^2 adjusted		**0.53**	

Bold: p<0.001; *: p<0.05; italic: p<0.1

Table 5. *Parameter estimates for the multivariate regression model estimating the distribution of movement densities for Üsküdar.*

	β	t	std β
avg. slope	-0.16*	-2.72*	-0.17*
setback distance	0.00	1.49	0.10
avg. sidewalk width	0.00*	2.00*	0.17*
avg. buffer width	-0.00	-0.15	-0.01
sidewalk maintenance	0.23	1.05	0.07
street trees [no]	-0.07	-0.63	-0.04
crosswalk existence [no]	-0.09	-0.78	-0.05
traffic signal existence [no]	0.14	0.58	0.06
street names [no]	-0.09	-0.80	-0.05
speed limit	-0.04*	-2.08*	-0.19*
Integration (800m)	0.00*	2.24*	0.25*
Choice (800m)	-0.00	-0.02	-0.00
Metric Reach (800m)	0.04	1.01	0.11
2-Directional Reach (20°)	0.04*	2.26*	0.25*
#residential land use (100m)	-0.02	-0.96	-0.07
#non-residential land use (100m)	**0.12**	**5.37**	**0.40**
residential land use density (100m)	-0.00	-0.62	-0.05
non-residential land use density (100m)	-0.00	-0.43	-0.03
N: 158			
R^2		**0.58**	
R^2 adjusted		**0.52**	

Bold: p<0.001; *: p<0.05; italic: p<0.1

4. Conclusions

The findings of this research lend specific support for three key findings, which may have implications for urban planning and urban design decisions aimed to reduce automobile dependence and induce non-auto commuting. These will be summarized under three headings: street network configuration, street design, and land use.

#1. Street network configuration is strongly associated with the distribution of pedestrian movement. The findings presented in this article confirm that the spatial structure of urban areas plays a significant role in the way movement densities of pedestrians are distributed in the city. It is shown that street network configuration, measured through syntactic measures of Integration and Choice at a radius of 800 meters as well as connectivity measures Metric Reach (800m) and 2-Directional Reach (20°), is strongly associated with movement densities when controlling for land use characteristics as well as street design attributes at the road segment scale. Linear models developed suggest that rather than the *to*- or *through*-movement potential of road segments, the density of street intersections has a greater impact on the distribution of flows. However, the results presented here also underscore the significance of the spatial structure of street networks, specifically the alignment of streets and the directional distance hierarchy engendered by the street network. The fact that direction changes are as important as metric distance in describing street network configuration points to the role of cognitive factors. While Metric Reach extends uniformly along the streets surrounding a given road segment, Directional Reach may ex-

Table 6. *Parameter estimates for the multivariate regression model estimating the distribution of movement densities for Ümraniye.*

	β	t	std β
avg. slope	-0.03	-0.47	-0.03
setback distance	0.00	0.52	0.04
avg. sidewalk width	0.00*	2.14*	0.18*
avg. buffer width	—	—	—
sidewalk maintenance	-0.25	-1.10	-0.08
street trees [no]	-0.02	-0.18	-0.01
crosswalk existence [no]	-0.05	-0.24	-0.02
traffic signal existence [no]	0.22	0.82	0.07
street names [no]	0.00	0.00	0.00
speed limit	-0.00	-0.39	-0.03
Integration (800m)	0.00	0.25	0.03
Choice (800m)	0.00*	2.29*	0.25*
Metric Reach (800m)	*0.10*	*1.78*	*0.17*
2-Directional Reach (20°)	0.05*	2.47*	0.18*
#residential land use (100m)	-0.02	-0.66	-0.10
#non-residential land use (100m)	**0.05**	**2.69**	**0.30**
residential land use density (100m)	0.00	0.74	0.10
non-residential land use density (100m)	0.00	1.44	0.12
N: 116			
R^2		**0.60**	
R^2 adjusted		**0.53**	

Bold: p<0.001; *: p<0.05; italic: p<0.1

Table 7. *Parameter estimates for the multivariate regression model estimating the distribution of movement densities for Ataşehir.*

	β	t	std β
avg. slope	*-0.11*	*-1.83*	*-0.12*
setback distance	-0.00	-0.10	-0.01
avg. sidewalk width	**0.00**	**3.49**	**0.28**
avg. buffer width	-0.00	-0.21	-0.02
sidewalk maintenance	-0.11	-0.52	-0.04
street trees [no]	0.08	0.94	0.07
crosswalk existence [no]	0.17	0.54	0.06
traffic signal existence [no]	-0.16	-1.15	-0.08
street names [no]	-0.04	-0.59	-0.04
speed limit	-0.01	-0.36	-0.03
Integration (800m)	-0.00	-0.61	-0.10
Choice (800m)	0.00	1.12	0.13
Metric Reach (800m)	**0.13**	**3.42**	**0.42**
2-Directional Reach (20°)	0.01	0.42	0.03
#residential land use (100m)	-0.02	-0.79	-0.06
#non-residential land use (100m)	**0.06**	**3.94**	**0.31**
residential land use density (100m)	0.00	0.12	0.01
non-residential land use density	-0.00	-0.06	-0.00
N: 158			
R^2		**0.50**	
R^2 adjusted		**0.43**	

Bold: p<0.001; *: p<0.05; italic: p<0.1

tend much less uniformly, because it is sensitive to the shape and alignment of streets, not merely to their density. This implies that street segments that constitute the primary connectivity skeleton holding together the street network is strongly associated with the way in which people navigate in urban space.

Traditional models of movement patterns are based on the consideration of distance and time, but they do not take into account the intelligibility of urban form. Integrating considerations of intelligibility can lead to enhanced models of urban form and function. The analyses presented in this paper suggest that it is possible to incorporate measures of street density and measures of cognitively significant configurational variables in the same model. However; it should be noted that the effect of spatial structure is not to determine pedestrian volume, but rather to explain how it is distributed. This is important for urban planners from the point of view of designing for urban liveliness. Space can shape land use patterns and urban densities, which are essential elements of lively cities, by affecting the distribution of pedestrian movement. To ensure urban liveliness the spatial configuration of an urban area must modulate movement densities in an economically viable manner to encourage multiple functions to occur simultaneously.

#2. Higher non-residential land uses designed at the ground floor level encourage walking. The spatial structure of street network does not work independently of land use. On the contrary, based on the standardized coefficients estimated in regression models, number of active uses opening directly onto the street segment is the main driver of the distribution of flows both for all areas considered as a single set and for individual areas summarized within their districts. This supports the findings of various studies highlighting the significance of the availability of non-residential destinations nearby pedestrian-oriented nodes, such as schools and transit stations, in walking behavior (Cervero, 2002; Lee, Zhu, Yoon, & Varni, 2013). To better understand the associations between land use compositions and movement densities, street segments are categorized in terms of their ground floor designs based on the number of non-residential uses associated with each segment, as developed by Gehl et al. (2006) and Gehl (2010). Streets are classified into 4 types: active/friendly (≥10 active uses per 100m with mostly small units); mixture (6-10 active uses with a mix of large and small units); boring (2-5 ac-

tive uses with many blind or uninteresting units); and inactive (0-2 active uses with blind or passive units). Here active uses indicate land uses, such as retail, office and commercial establishments, dependent on passerby movement for economic viability. Figure 7 shows street scenes from four different study areas demonstrating the classification of street types based on their ground floor design.

The Student's *t* test ($p<0.05$) was used for comparing the distribution of movement densities between street types. One-way ANOVA was used for comparison of street types. As shown in Figure 8, comparisons between street types, namely active/friendly, mixture, boring, and inactive, confirm the considerable range of variation within flows at each. The coefficient of determination is 0.41 and it is significant at a 99% level of confidence. Comparison between their means also points to substantial differences in movement densities. Results of Student's *t* test, presented in Table 9, indicate that there is a significant difference between each pair of types with regard to their walking shares.

This analysis has consequences for at least some kinds of local urban economy: in İstanbul retail still relies on the "passing trade" because of the finer grain not only of the street network but also the size of businesses. The prevalent trait in the city, where ground floors of most residential uses function as small retail/commercial shops spread within the entire neighborhood, contributes to the higher rates of pedestrian flow encouraged by the higher street connectivity in terms of density. Here the term density refers to the amount of street which is available within a given metric range. The results also indicate that it is the number of non-residential frontages at the ground floor level rather than the gross densities of non-residential land uses at the road segment scale that matter for the distribution of movement densities within the urban fabric.

It can be concluded that streets with commercial activity on the ground floor including shops, banks, cafes, and other services, are usually more stimulating to the passerby, attracting peo-

Table 8. *Parameter estimates for the multivariate regression model estimating the distribution of movement densities for Kartal.*

	β	t	std β
avg. slope	0.11	1.83	0.12
setback distance	-0.00	-0.10	-0.01
avg. sidewalk width	**0.00**	**3.49**	**0.28**
avg. buffer width	-0.00	-0.21	-0.02
sidewalk maintenance	-0.11	-0.52	-0.04
street trees [no]	0.08	0.94	0.07
crosswalk existence [no]	0.17	0.54	0.06
traffic signal existence [no]	-0.16	-1.15	-0.08
street names [no]	-0.04	-0.59	-0.04
speed limit	-0.00	-0.36	-0.03
Integration (800m)	-0.00	-0.61	-0.10
Choice (800m)	0.00	1.12	0.13
Metric Reach (800m)	**0.13**	**3.42**	**0.42**
2-Directional Reach (20°)	0.08	0.42	0.03
#residential land use (100m)	-0.01	-0.79	-0.06
#non-residential land use (100m)	**0.06**	**3.94**	**0.31**
residential land use density (100m)	0.00	0.12	0.08
non-residential land use density (100m)	-0.00	-0.06	-0.00
N: 120			
R^2		**0.50**	
R^2 adjusted		**0.43**	

Bold: $p<0.001$; *: $p<0.05$; italic: $p<0.1$


a.
b.
c.
d.

Figure 7. *Classification of streets based on the numbers of non-residential uses at the ground floor level, described as (a) active/friendly, (b) mixture, (c) boring, and (d) inactive. Developed based on Gehl et al. 2006 and Gehl 2010.*

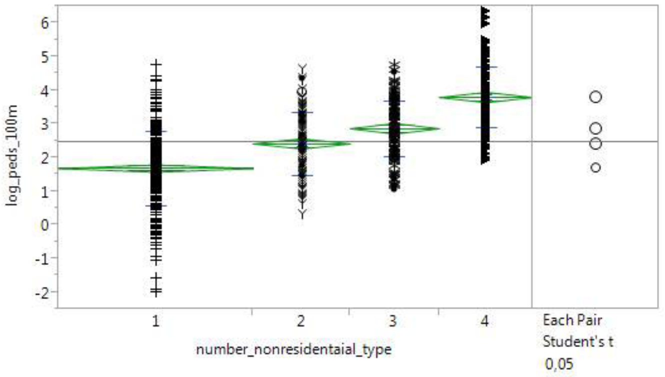


Figure 8. *Variations in pedestrian densities between street types as defined by the number of non-residential ground-floor uses.*

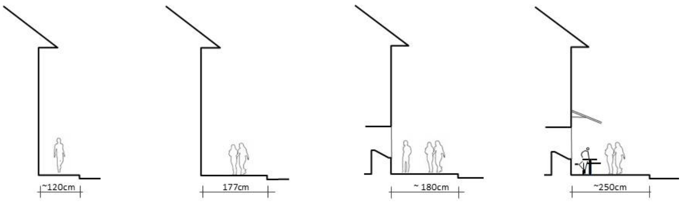
Table 9. *Results of comparisons of means of street types using Student's t test.*

type	type	difference	std err dif	lower CL	upper CL	p-value
4	1	2.1507	0.0945	1.9651	2.3363	**<0.0001**
4	2	1.4271	0.1093	1.2126	1.6416	**<0.0001**
3	1	1.2024	0.0967	1.0127	1.3922	**<0.0001**
4	3	0.9482	0.1113	0.7298	1.1667	**<0.0001**
2	1	0.7235	0.0943	0.5384	0.9087	**<0.0001**
3	2	0.4789	0.1111	0.2608	0.6970	**<0.0001**

N=800

ple from immediate surroundings and further away areas. From the models it is evident that pedestrian movement is sensitive to the number of active uses opening directly onto the street both in the traditional urban areas, such as Kadıköy and Üsküdar, and contemporary in-town residential areas, such as Ataşehir, as well as peripheral districts, such as Ümraniye and Kartal. However; the higher significance and effect levels of this variable in the regression models for Kadıköy and Üsküdar indicate that since streets with commercial frontage are more evenly distributed and integrated within the surrounding urban fabric in central areas than in peripheral districts, pedestrian movement is more tuned to the ground floor-level land uses than other urban design and configurational features. Therefore, the lesson urban designers should take from these findings is that the strategic design of the ground floor at the road segment scale is critical in designing for urban vitality and sustainability; hence, is directly related to the quality of urban life.

#3.The main contribution of this article, however, is the explicit consideration of street design. Findings of this study are consistent with earlier findings arguing that sidewalk design provisions seem to be strong predictors of walking behavior (Alfonzo, Boarnet, Day, Mcmillan, & Anderson, 2008). The models developed indicate that average sidewalk width is significantly and positively associated with movement densities over and above other urban design features. In fact, the results indicate that pedestrian movement is sensitive to average sidewalk both in central city and peripheral districts. The average sidewalk width for all areas is found to be 177cm while ¼ of street segments have an average sidewalk width less than 118cm. One practical implication of this finding would be the provision of more generous sidewalks on spatially more prominent streets in the light of the association between measures of street network configuration and movement densities. Also, extensive sidewalks should be a higher priority in areas which have denser street intersections and a clearer internal hierarchy of access based on directional distances. Figure 9 illustrates various street section types with different sidewalk widths and ground floor designs to accommodate differing movement densities. As such, this study offers rules of thumbs for urban designers with regard to quality of urban life.



section type 'a' section type 'b' section type 'c' section type 'd'

Figure 9. *Different street sections characterizing less active space with a lower potential of generating movement (section type 'a') to more active spaces with a higher potential for movement densities (section types 'b', 'c', and 'd'). Modified from Gehl (2010).*

The enhanced model of pedestrian movement demonstrated in this paper can inform specific urban design and urban master planning decisions, since it incorporates measures that can address alternative street alignments and the density of street connections simultaneously, in addition to street design attributes and land use compositions at various scales. Furthermore, the model can mediate between urban design and architectural design given the fact that the urban situations of buildings and land uses that can be accommodated at the ground level are sensitive to frontage and the character of the associated street. Therefore, future studies should focus on different attributes of street design, including but not limited to street widths, in conjunction with street network configuration and land use compositions both at ground floor-level and road segment-scale.

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References

Agrawal, A. W., Schlossberg, M., & Irvin, K. (2008). How Far, by Which route and why? A Spatial Analysis of Pedestrian Preference. *Journal of Urban Design, 13*, 81–98.

Alfonzo, M., Boarnet, M. G., Day, K., Mcmillan, T., & Anderson, C. L. (2008). The Relationship of Neighbourhood Built Environment Features and Adult Parents' Walking. *Journal of Urban Design*, *13*(1), 29-51.

Appleyard, D. (1982). *Livable Streets*. University of California Press.

Badland, H., & Schofield, G. (2005). Transport, Urban Design, and Physical Activity: An Evidence-Based Update. *Transportation Research Part D: Transport and Environment, 10*(3), 177–196.

Bailenson, J. N., Shum, M. S., & Uttal, D. H. (2000). The Initial Segment Strategy: A Heuristic for Route Selection. *Memory & Cognition*, *28*(2), 306–318.

Boarnet, M. G., Anderson, C. L., Day, K., McMillan, T., & Alfonzo, M. (2005). Evaluation of the California Safe Routes to School legislation: Urban Form Changes and Children's Active Transportation to School. *American Journal of Preventive Medicine*, *28*, 134–140.

Boarnet, M., & Sarmiento, S. (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*(7), 1155–1169.

Brown, B. B., Werner, C. M., Amburgey, J. W., & Szalay, C. (2007). Walkable Route Perceptions and Physical Features: Converging Evidence for En Route Walking Experiences. *Environment and Behavior*, *39*(1), 34–61.

Cao, X., Mokhtarian, P. L., & Handy, S. L. (2007). Do Changes In Neighborhood Characteristics Lead to Changes in Travel Behavior? A Structural Equations Modeling Approach. *Transportation, 34*(5), 535–556.

Cervero, R. (2002). Built Environments and Mode Choice: Toward a Normative Framework. *Transportation Research Part D: Transport and Environment, 7*(4), 265–284.

Cervero, R., & Kockelman, K. (1997). Travel demand and the 3Ds: Density, diversity, and design. Transportation *Research Part D: Transport and Environment, 2*(3), 199–219.

Cervero, R., & Radisch, C. (1995). Travel Choices in Pedestrian Versus Automobile Oriented Neighborhoods. *Transport Policy, 3*(3), 127–141.

Crowe, D. A., Averbeck, B. B., Chafee, M. V., Anderson, J. H., & Georgopoulos, A. P. (2000). Mental Maze Solving. *Journal of Cognitive Neuroscience, 12*(5), 813–827.

Ewing, R., Brownson, R. C., & Berrigan, D. (2006). Relationship Between Urban Sprawl and Weight of United States Youth. *American Journal of Preventive Medicine, 31*(6), 464–74.

Ewing, R. H. (1996). *Best Development Practices : Doing the Right Thing and Making Money at the Same Time*. Chicago : American Planning Association.

Ewing, R., & Handy, S. (2009). Measuring the Unmeasurable: Urban Design Qualities Related to Walkability. *Journal of Urban Design, 14*(1), 65–84.

Frank, L. D. (2000). Land Use and Transportation Interaction: Implications on Public Health and Quality of Life. *Journal of Planning Education and Research, 20*(1), 6–22.

Frank, L. D., & Engleke, P. (2000). How Land Use and Transportation Systems Impact Public Health : A Literature Review of the Relationship Between Physical Activity and Built Form. *Environments*. Atlanta, GA.

Frank, L. D., & Pivo, G. (1994). Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single Occupant Vehi- Cle, Transit, and Walking. *Transportation Research Record: Journal of the Transportation Research Board, 1466*, 44–52.

Gehl, J. (2010). *Cities for People*. London: Island Press

Gehl, J. (2011). *Life Between Buildings: Using Public Space*. London: Island Press

Gehl, J., Kaefer, L. J., & Reigstad, S. (2006). Close Encounters with Buildings. *Urban Design International, 11*(1), 29–47.

Giles-Corti, B., & Donovan, R. J. (2002). The Relative Influence of Individual, Social and Physical Environment Determinants of Physical Activity. *Social Science & Medicine, 54*(12), 1793–812.

Goldberg, D., Frank, L., Chapman, J., Kavage, S., & Mccann B. (2007). *New Data for a New Era: A Summary of SMARTRAQ Findings*. San Francisco: Smartraq Technical Report.

Greenwald, M. J., & Boarnet, M. G. (2001). *The Built Environment as a Determinant of Walking Behavior: Analyzing Non-Work Pedestrian Travel in Portland, Oregon*. Institute of Transportation Studies: Irvine

Handy, S. (1996). Methodologies for Exploring the Link Between Urban Form and Travel Behavior. *Transportation Research Part D: Transport and Environment, 1*(2), 151–165.

Handy, S. (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.

Handy, S., & Clifton, K. (2001). Evaluating Neighborhood Accessibility: Possibilities and Practicalities. *Journal of Transportation and Statistics, 4*, 67–78.

Handy, S. L. (1992). Regional Versus Local Accessibility: Neo-Traditional Development and Its Implications for Non-Work Travel. *Built Environment, 18*(4), 253–267.

Hess, P. M., Muodon, A. V., Snyder, M. C., & Stanilov, K. (1999). Site Design and Pedestrian Travel. *Transportation Research Record, 1674*, 9–19.

Hillier, B., & Iida, S. (2005). *Network effects and psychological effects: a theory of urban movement*, 5th International Symposium on Space Syntax, Delft.

Hillier, B., Penn, A., Hanson, J., Grajewski, T., & Xu, J. (1993). Natural Movement - Or, Configuration And Attraction In Urban Pedestrian Movement. *Environ Plann B., 20* (1), 29 - 66.

Hillier, W., Yang, T., & Turner, A. (2012). Normalising Least Angle Choice in Depthmap - And How It Opens up New Perspectives on The Global and Local Analysis of City Space. *Journal of Space Syntax*, *3*(2), 155-193.

Humpel, N., Owen, N., & Leslie, E. (2002). Environmental Factors Associated with Adults' Participation in Physical Activity: *A Review. American Journal of Preventive Medicine, 22*(3), 188–99.

Jansen-Osmann, P., Wiedenbauer, G. (2004). The Influence of Turns on Distance Cognition: New Experimental Approaches to Clarify the Route-Angularity Effect. *Environment and Behavior, 36*(6), 790–813.

Krizek, K. J. (2003). Residential Relocation and Changes in Urban Travel: Does Neighborhood-Scale Urban Form Matter? *Journal of the American Planning Association, 69*(3), 265–281.

Lee, C., & Moudon, A. V. (2006). The 3Ds+R: Quantifying Land Use and Urban Form Correlates of Walking. *Transportation Research Part D: Transport and Environment, 11*(3), 204–215.

Lee, C., Zhu, X., Yoon, J., & Varni, J. W. (2013). Beyond Distance: Children's School Travel Mode Choice. *Annals of Behavioral Medicine, 45*(1), 55–67.

Marshall, N., & Grady, B. (2005). Travel Demand Modeling for Regional Visioning and Scenario Analysis. *Transportation Research Record: Journal of the Transportation Research Board, 1921*, 44–52.

Matley, T. M., Goldman, L. M., & Fineman, B. J. (2001). Pedestrian Travel Potential in Northern New Jersey: A Metropolitan Planning Organization's Approach to Identifying Investment Priorities. *Transportation Research Record, 1705*.

Montello, D. R. (1991). The Measurement of Cognitive Distance: Methods and Construct Validity. *Journal of Environmental Psychology, 11*(2), 101–122.

Oakes, J. M., Forsyth, A., & Schmitz, K. H. (2007). The Effects of Neighborhood Density and Street Connectivity on Walking Behavior: The Twin Cities Walking Study. *Epidemiologic Perspectives & Innovations : EP+I, 4*(1), 16.

Ozbil, A., & Peponis, J. (2012). *The Effects of Urban Form on Walking to Transit.* Eigth International Space Syntax Symposium, Chile.

Parsons Brinkerhoff Quade & Douglas Inc., C. S. & C. A. (1993). Making the Land Use, Transportation, Air Quality Connection (LUTRAQ), National Transportation Library, Oregon.

Peponis, J., Bafna, S., & Zhang, Z. (2008). The Connectivity of Streets: Reach and Directional Distance. *Environment and Planning B: Planning and Design, 35*(5), 881–901.

Peponis, J., Ross, C., & Rashid, M. (1997). The Structure of Urban Space, Movement and Co-Presence: The Case of Atlanta. *Geoforum, 28*(3-4), 341–358.

Rajamani, J., Handy, S., Bhat, C., Knaap, G., Song, Y. (2003). *Assessing The Impact of Urban Form Measures on Nonwork Trip Mode Choice After Controlling for Demographic and Level-Of-Service Effects*. Paper presented at TRB Annual Meeting.

Reilly, M. , Landis, J.(2002). *Influence of Urban Form and Land Use on Mode Choice: Evidence From the 1996 Bay Area Travel Survey*. Institute of Urban and Regional Development University of California, Berkeley.

Rodríguez, D. A., Aytur, S., Forsyth, A., Oakes, J. M., & Clifton, K. J. (2008). Relation of Modifiable Neighborhood Attributes to Walking. *Preventive Medicine, 47*(3), 260–4.

Rodriguez, D. A., & Joo, J. (2004). The Relationship between Non-Motorized Mode Choice and the Local Physical Environment. *Transportation Research Part D: Transport and Environment, 9*(2), 151–173.

Sadalla, E. K., & Magel, S. G. (1980). *The Perception of Traversed Distance. Environment and Behavior, 12*(1), 65–79.

Saelens, B. E., Sallis, J. F., & Frank, L. D. (2003). Environmental Correlates of Walking and Cycling: Findings From the Transportation, Urban Design, and Planning Literatures. *Annals of Behavioral Medicine : A Publication of the Society of Behavioral Medicine, 25*(2), 80–91.

Sallis, J. F., Johnson, M. F., Calfas, K. J., Caparosa, S., & Nichols, J. F. (1997). Assessing Perceived Physical Environmental Variables that May Influence Physical Activity. *Research Quarterly for Exercise and Sport, 68*(4), 345–351.

Sallis, J. F., Owen, N., & Fotheringham, M. J. (2000). Behavioral Epidemiology: A Systematic Framework to Classify Phases of Research on Health Promotion and Disease Prevention. *Annals of Behavioral Medicine : A Publication of the Society of Behavioral Medicine, 22*(4), 294–8.

Sallis, J. F., Prochaska, J. J., & Taylor, W. C. (2000). A Review of Correlates of Physical Activity of Children and Adolescents. *Medicine and Science in Sports and Exercise, 32*(5), 963–75.

U.S. Department of Health and Human Services (1996). *Physical Activity and Health: A Report of the Surgen General.* Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion.

Shriver, K. (1997). Influence of Environmental Design on Pedestrian Travel Behavior in Four Austin Neighborhoods. *Transportation Research Record: Journal of the Transportation Research Board*, 1578, 64–75.

Song, Y. (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.

Timperio, A., Ball, K., Salmon, J., Roberts, R., Giles-Corti, B., Simmons, D., Baur, L. A., & Crawford, D. (2006). Personal, family, social, and environmental correlates of active commuting to school. *American Journal of Preventive Medicine, 30*(1), 45–51.

Turner, A. & Friedrich, E. (2010-2011). *Depthmap Software, Version 10.14.00b*. University College London: London.

Yürünebilirliğin modellenmesi: sokak tasarımı, yol-ağı örgütlenmesi ve arazi kullanımının yaya hareketine etkisi

Bu çalışma sokak tasarımı –sokak çevresinin yerel nitelikleri-, yol-ağı örgütlenmesi –kentsel dokunun mekânsal yapısı-, ve arazi kullanım örüntüsünün yaya hareket dağılımıyla olan ilişkisini incelemektedir. Çalışmanın amacı, sistematik olarak ölçülen yol ölçekli kentsel tasarım nitelikleri ile nesnel olarak ölçülen yol-ağı örgütlenmesinin yaya hareketi ve arazi kullanımı ile arasında ne derecede bir bağıntı olduğunu ortaya koymaktır.

Sokak tasarımı, yol örgütlenmesi ve yaya hareket yoğunlukları arasındaki bağıntıyı ortaya koymak için İstanbul'un Anadolu yakasında seçilen 20 adet 2kmx2km'lik alan çalışılmıştır. Yaya yoğunlukları ile ilgili veriler alan içinden seçilen yol-parçalarında gerçekleştirilen yaya sayımları aracılığıyla elde edilmiştir. Aynı yol-parçaları; estetik nitelikler, sokak işaretleri, kaldırım tasarımı, yaya geçitleri/trafik ışıkları, giriş katı kullanımları ve CBS kaynaklı parsel ölçekli arazi kullanım yoğunlukları ve sokak ölçekli topografya verileri bağlamında detaylı saha analizlerine tabi tutulmuştur. Alanlardaki yol-ağı örgütlenmesi açısal yol-parçası analizi (Bütünleşme ve Tercih) ile parametrik bağıntılılık ölçütleri (Metrik ve Açısal Erişim) ile değerlendirilmiştir. Sokak tasarımı, yol-ağı örgütlenmesi, arazi kullanımı ve yürüme davranışı arasındaki ilişkiyi incelemek için doğrusal modelleme yöntemi kullanılmıştır.

Bu çalışma, sokak çevresinin kentsel tasarım niteliklerinin ve sokak ağı örüntüsünün yaya hareketi üzerindeki karşılaştırmalı rollerine dair ortaya koyduğu bulgularla önceki çalışmalara katkıda bulunmaktadır. Ön bulgular; -sokak çevresinin yerel kentsel tasarım nitelikleriyle ilintili bazı özelliklerinin önemi göz ardı edilmeksizin- yol ağının genel mekânsal örgütlenmesinin, yaya hareketinin tanımlanması ve düzenlemesinde önemli bir değişken olduğunu göstermektedir.

Modeling walkability: The effects of street design, street-network configuration and land-use on pedestrian movement