118

Walking to school:

The effects of street network configuration and urban design qualities on route selection behaviour of elementary school students

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Abstract

This study examines the association of spatial layout of street networks and urban design qualities of the street environment with path selection by elementary school students. The aim is to better understand the extent to which objectively measured street network configuration and systematically measured urban design qualities are related to pedestrian route choice behaviour. Within this scope, randomly selected 6th, 7th, and 8th grade students (ages 12-14) from 10 elementary schools (30 students per school) in Istanbul, Turkey were asked to draw their routes walking between home and school. The schools were drawn from diverse neighbourhoods that vary substantially in education and walkability (street connectivity patterns). Street network configuration of the entire region was evaluated by using angular segment analysis (integration and choice) implemented in depthmapX as well as two segment-based 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. 40 street segments along the selected routes for each school (N=400) were characterized through detailed field surveys in terms of five perceptual urban design qualities that are prevalent in urban design literature: imageability, enclosure, human scale, transparency, and complexity. These are measured in terms of the physical features of the street environment including but not limited to buildings, sidewalks, and street items (i.e. trees). Linear models were developed to investigate the relationships among street network configuration, urban design qualities, and route choice behaviour of school students. This study contributes to the literature by offering insights into the comparative roles of street network layout and urban design qualities of the street environment in explaining urban navigation behaviour of children. Preliminary findings imply that notwithstanding the significance of safety attributes, such as the presence of pedestrian crossings and traffic signals as well as the number of vehicular lanes along the selected routes, the overall spatial configuration of urban layouts –both at the local and global level– may prove to be a significant variable for the description and modulation of human spatial behaviour in urban environments. Moreover, results indicate that route selection during target-directed walking is sensitive to certain aspects of the street environment that relate to more perceptual urban design qualities.

Keywords

Route selection behaviour, spatial cognition, urban design qualities, street network configuration, Istanbul.

1. Introduction

There is a considerable body of literature on walking behaviour and strategies pedestrians perform when navigating through the built environment. Yet route choice still remains one of the most interesting and challenging theoretical and practical problems in describing pedestrian travel. Related literature has emphasized the importance of the urban environment in influencing navigation choices. The majority of studies evolve around two primary attributes of the walking environment: perceptual qualities (urban design qualities of the street environment that may affect the walking experience) and cognitive qualities (street network characteristics shown to impact the cognitive effort required to navigate through an area) of the urban environment.

Researches investigating the perceptual environmental correlates of walking have focused on the local correlates of the street environment often characterised in terms of street crossings, attractive landscaping, tree covers, and signalization (Agrawal et al., 2008; Cao et al., 2007), as well as aesthetic or safety features, such as cleanliness, interesting sights, and architecture (Appleyard, 1982; Gehl, 2011). One of the problems associated with the typical range of environmental attributes considered is the lack of consensus on the measures to be included in studies. For example, prior studies have reported conflicting and limited evidence on the effects of sidewalk availability for walking (Sallis et al., 1997). Findings with regard to land-uses, on the other hand, mostly agree that having destinations within walking distance from origins (homes, stations, schools, etc.) increase the odds of walking (Frank and Engleke, 2000; Handy and Clifton, 2001).

A second limitation is related to the unit of analysis used in characterising the street environment. As the majority of studies examine the shortest routes between origins and destinations, failure to consider the actual paths walked by respondents poses a real challenge in clearly understanding the environmental correlates of walking behaviour. Moreover, empirical evidence offered by these studies is still limited in terms of the specific urban design qualities related to walking behaviour of children. Studies on children’s navigation patterns demonstrate that while certain environmental attributes, such as the presence of street trees and sidewalks, are commonly correlated with adults’ and children’s walking behaviour, other features, such as mixed land-use, may differ in their associations (Larsen et al., 2012).

Another challenge is defining commonly accepted tools and methodologies for measuring the urban design quality of the walking environment. Using walking audit instruments to measure the physical features, such as building height and sidewalk width, is one way of addressing this problem. A more systematic method is through consensus building strategies, such as the study conducted by Ewing et al. (2006) in which a multi-disciplinary panel of experts was consulted to identify operational definitions and measurement protocols for five subjective qualities of urban design: imageability, enclosure, human scale, transparency, and complexity. The instrument developed by this study, which has been tested and validated by empirical data from other researchers, provides a consistent tool for objectively measuring the perceptual qualities of the urban environment.

Evaluating such perceptual and local 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. Empirical evidence suggests that the structure of an urban street network, as defined by the connectivity hierarchy measured by direction changes, plays an important role in pedestrian travel (Hillier and Iida, 2005; Ozbil et al., 2011). This 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 (Conroy Dalton, 2003; Jansen-Osmann and Wiedenbauer, 2004). 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 walkable environments.

2. Method

Despite the growing body of research on pedestrian travel, few studies have employed street-level analysis (vs. larger units of analysis such as census tracts, or block groups) accounting for fine-grained design aspects essential to understanding travel behaviour within an area of a few square miles. Even fewer studies have examined simultaneously assessed perceived urban design qualities and objectively measured street network accessibility in affecting children's route selection in commuting to school. This study examines multiple aspects of the environment, including street-level urban design qualities, physical features of the street environment, and street network configuration for route selection during walking to/from-school (Figure 1).

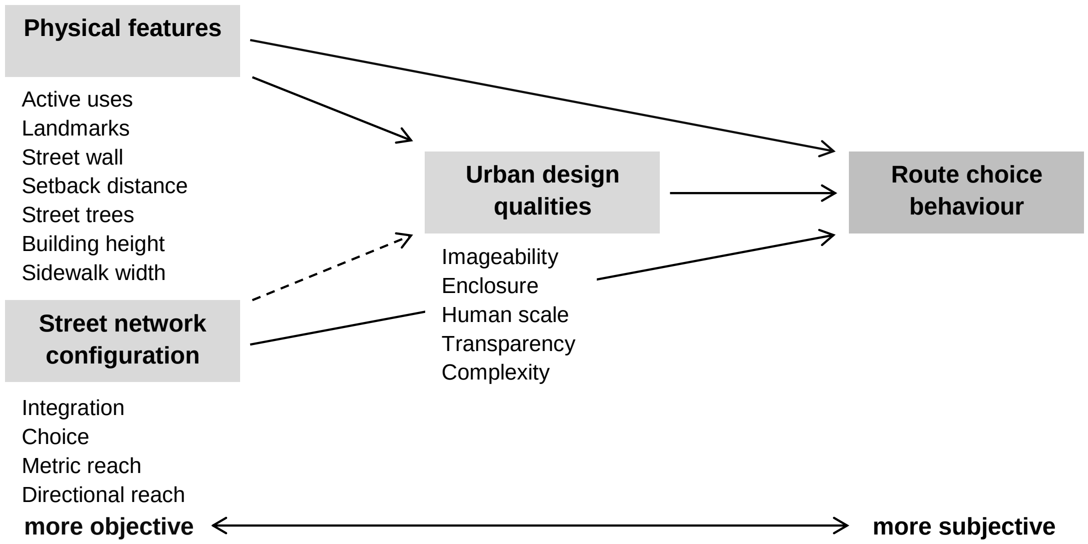

Figure 1. Method of study showing the interaction of multiple attributes of the street environment in affecting route choice behaviour in urban navigation. Reproduced by the authors based on the figure in Ewing et al. (2006, p.225).

2.1 Data collection

Two primary methods of data collection were implemented in this study: a face-to-face survey to determine children's actual routes walking between home and school; and street environment audits to objectively measure urban design qualities along these routes. Children included in this analysis were sampled through 10 primary elementary schools in Istanbul, Turkey. The schools were drawn from four districts (Kadikoy, Uskudar, Atasehir and Umraniye) of Anatolian part of the city. They are located in diverse neighbourhoods that vary substantially in education and walkability (street connectivity patterns), as shown in Figure 2.

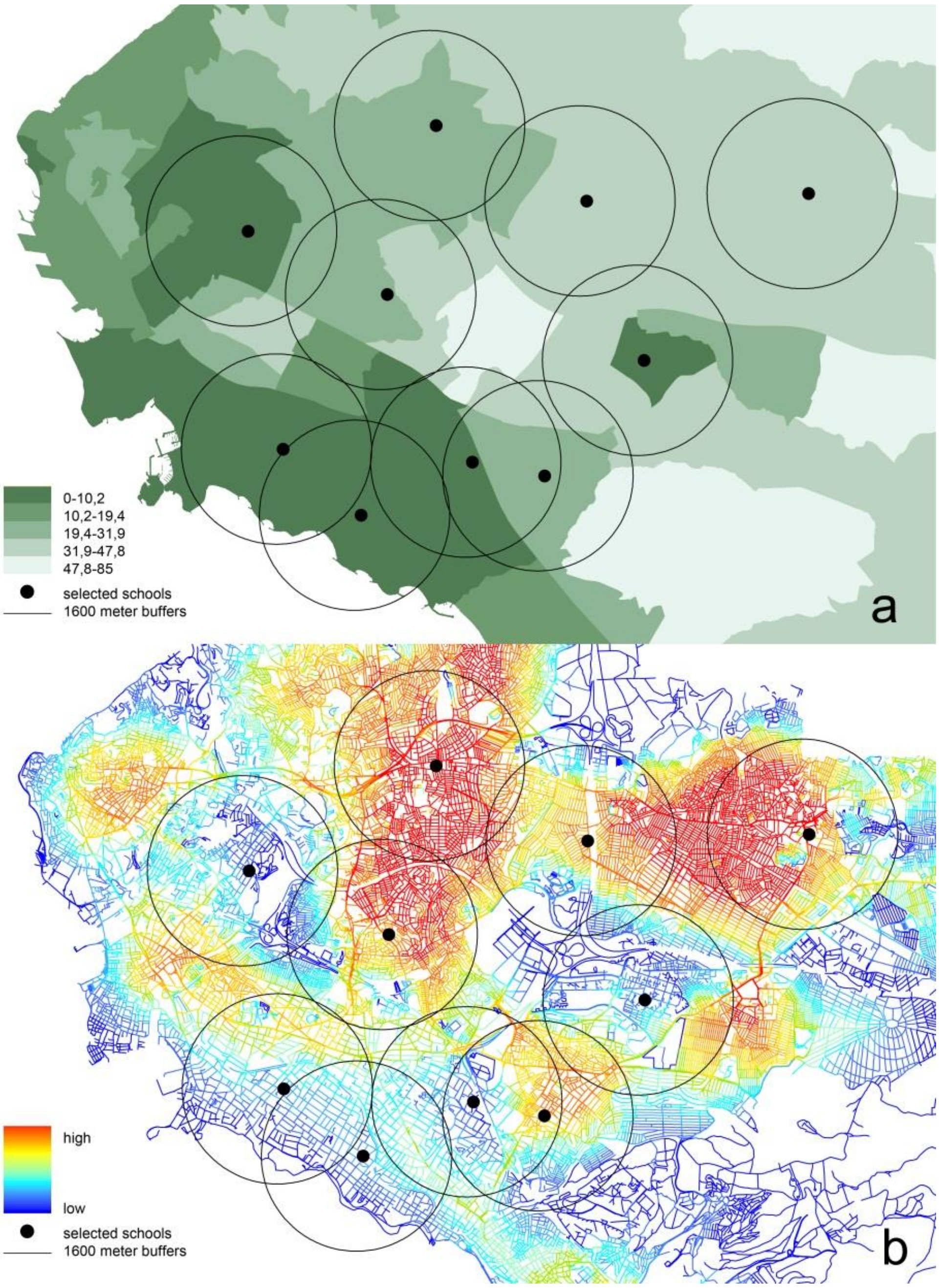

Figure 2. Location of surveyed schools. Maps are coloured based on (a) the district-based average education levels, and (b) Metric Reach (1600m) values of the street network.

Randomly selected 6th, 7th, and 8th grade students (ages 12-14) (N=1000, 100 students per school) were asked to report their mode of transportation for home-school journeys, and those reported walking in either leg of the trip (N=663) were asked to draw their routes on a map (Figure 3). Each student was guided on a smart-phone-based street map to ensure the accuracy of the drawn route and starting points of their routes were compared with their geocoded addresses. Detailed street environment audits were conducted within 1600-metre (1mile) walkable-rings around schools during daylight hours to collect comprehensive data on street environment and pedestrian densities. Due to resource limitations, only 40 street segments along the selected routes were sampled from each school area. Hence, a total number of 400 street segments were audited, and the average length of audited segments was 118 metres.

Figure 3. All walking routes of surveyed students from two schools (buffers denote 1600m-radius).

2.2 Measures

2.2.1 Urban design qualities

Street segments were characterized through detailed field surveys in terms of five perceptual urban design qualities that are prevalent in urban design literature: imageability, enclosure, human scale, transparency, and complexity. These were measured based on the operational definitions identified and validated in Ewing and Clemente (2013). The particular study was adopted as the roadmap on two accounts. First, it offers systematic and comprehensive definitions to objectively quantify subjective characteristics of the urban street environment. Second, the instrument has been tested and validated both by lay observers and empirical data offered by case studies. The appropriate environmental attributes identified in this study were adapted to measure urban design qualities of the street segments. Some (i.e. noise level, street furniture) were eliminated due to resource limitations.

Imageability includes the total number of people, retail and recreational uses, and landmarks (mosques and historic buildings) along the route, relativized by street length (per 100m). Enclosure consists of proportion street wall (height-width ratio: proportion of the average length of continuous building facades and high walls on both sides to the length of the segment), setback distance (average distance between sidewalks and buildings), and the presence of street trees. Human scale includes the average building height and width of sidewalks along the audited street segment. Transparency incorporates the proportion of active uses (proportion of the total number of retail, commercial, and institution uses to the total number of destinations along the segment), total number of non-residential uses (per 100m) and proportion street wall. Lastly, complexity includes the total number of buildings, pedestrians and retail activities along the audited segment, relativized by street length (per 100m).

Physical features of the street environment shown to affect navigation in urban environments through their impacts on pedestrians' perceptions were also included in the analysis. These are grouped into transportation environment and social environment. Transportation environment includes the presence of street signs, number of pedestrian crossings and traffic-signals, speed limit, sidewalk width (average width on both sides), and sidewalk maintenance measured dichotomously for each segment. Social environment, which contains the total number of doors and pedestrians on audited segments relativized by street length (per 100m), measures the degree of surveillance along the streets.

2.2.2 Street network configuration

Street network configuration of school-environments was evaluated using angular segment analysis (Integration and Choice) implemented in depthmapX 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 Angular Choice* which measures how many times a space is selected on journeys between all pairs of origins and destinations (Hillier and Iida, 2005). These two measures represent the *to* and *through* movement potentials of the street segments (Hillier et al., 2012). Global Choice and global Integration within 1600 metre buffers as well as local Choice and local Integration for 400-, 800-, and 1600-m radii were calculated.

Street network configuration of the entire region was also evaluated by using two segment-based measures of connectivity; *Metric Reach* and *Directional Reach* (Peponis et al., 2008). In Metric Reach analysis, the density of streets and street connections accessible from each individual street segment are captured by measuring the total street length accessible from each street segment up to a parametrically specified metric distance threshold. In Directional Reach analysis, the extent to which the entire street network is accessible with few direction changes is captured by measuring 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 400, 800, and 1600 metre 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. Measuring 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. Figure 4 illustrates global Integration, global Choice, Metric Reach (1600m), and 2-directional Reach (20^o) respectively.

a. Integration (n) **b.** Choice (n) **c.** Metric Reach (1600m) **d.** 2-directional Reach (20^0)

Figure 4. Representing a school-environment (1600 m-radius) with different configurational measures.

3. Results

Regression analyses were conducted to examine the associations between urban design qualities, physical features, and configurational measures in explaining route choice behaviour. Three sets of models were produced. The first set of models includes urban design qualities –imageability, enclosure, human scale, transparency, and complexity– and physical features of the street environment. In the respective models syntactic measures and connectivity measures were added to the model separately to allow for the evaluation of configurational variables in context relative to other factors affecting route choice and to compare the contributions of each measure to the overall model. The results from the three sets of regression models are presented in Table 1. Since configurational measures computed for 1600 metre radius produced higher coefficients in the analyses, these measures are reported in the tables. Logarithmic transformation was applied to the dependent variable (frequency of segments selected) and independent variable total number of pedestrians (per 100m) as their distributions indicated some degree of skewness.

		+ syntactic measures	+ connectivity measures			+ syntactic measures	+ connectivity measures
IMAGEABILITY				**TRANSPARENCY**			
pedestrians	0,232***	0,213***	0,225***	**street wall**	0.053	0,061	0,060
retail	0,066	0,052	0,070	**active uses**	0.244***	0,203***	0,222***
recreation	-0,020	-0,01	-0,020	**Choice (n)**		0,148**	
landmarks (yes)	-0.060	-0.051	-0.053	**Integration (n)**		-0,050	
Choice (n)		0,136**		**Metric Reach**			-0,100
Integration (n)		-0,030		**Directional Reach**			0,120**
Metric Reach			-0,150	**COMPLEXITY**			
Directional Reach			0,065	**pedestrians**	0,231***	0,218***	0,224***
ENCLOSURE				**retail**	0,119	0,076	0,114
setback	0.098*	0,079	0,077	**buildings**	-0,070	-0,030	-0,050
street trees (yes)	0.040	0,060	0,030	**Choice (n)**		0,144**	
street wall	0.062	0,068	0,067	**Integration (n)**		-0,160	
Choice (n)		0,098*		**Metric Reach**			-0,160
Integration (n)		0,257		**Directional Reach**			0,068
Metric Reach			0,029	**PHYSICAL FEATURES**			
Directional Reach			0,183***	**signs (yes)**	0,090*	0,080*	0,090*
HUMAN SCALE				**speed limit**	0,067	0,051	0,073
active uses	0,199***	0,168***	0,196***	**traffic signals**	-0,050	-0,04	-0,040
building height	0,044	0,040	0,049	**crosswalks**	0,049	0,036	0,045
sidewalk width	0,122**	0,114**	0,096*	**sidewalk maintenance (yes)**	0,070	0,060	0,080*
Choice (n)		0,143**		**sidewalk width**	0,055	0,060	0,037
Integration (n)		-0,100		**pedestrians**	0,192***	0,184***	0,205***
Metric Reach			-0,080	**buildings**	0,041	0,040	0,043
Directional Reach			0,081	**Choice (n)**		0,128**	
				Integration (n)		-0,180	
				Metric Reach			-0,180
				Directional Reach			0,029

*p<0.10; **p<0.05; ***p<0.01

Table 1. Standardized Beta coefficients from three sets of regression models predicting urban design qualities, physical features of the street environment, and configuration of street layout.

For imageability, only the distribution of pedestrian movement along the street segments showed strong positive associations with the frequency of street selection. For enclosure, the only significant correlate was setback distance, though with a marginal significance. For human scale, however, higher proportion of active uses and mean sidewalk width predicted higher frequencies of selected routes. For transparency, similar results were obtained with only the proportion of active uses proving to be the significant correlate. Similar to imageability, pedestrian distribution along streets correlated significantly and positively with route selection for both complexity and physical features of the street-environment. However, several additional variables became significant for physical features, including the presence of street labels /signs (positive) and sidewalk maintenance (positive).

When global Choice and global Integration were added to the models, the overall results were similar to the previous model. From the syntactic measures, only global Choice entered as a significant configurational measure. In all models, the standardized coefficient for global Choice is positive and statistically significant. In the final set of regressions, connectivity measures Metric Reach and Directional Reach were entered into the models together with urban design qualities and physical features. While Metric Reach failed to correlate with the frequency of selected segments, Directional Reach entered as a significant variable only along with enclosure and transparency variables.

Finally, the urban design quality attributes, physical features and configurational measures 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 route choice. Since there was strong multicollinearity between global Integration and Metric Reach (r^2=0.79, p<0.001), these measures were included separately in the overall model. The results were similar. Table 2 shows the effect levels of variables included in the stepwise regression model using Metric Reach. A variable measuring the straight-line distance between each segment and the related school, measured from the midpoint of the segment, was also added.

The results suggest that the primary factors in explaining route selection are the distance of the street to the school (negative) along with the variations in-between school-environments and pedestrian distributions within the network (positive). While adding the distance variable to the model results in a considerable increase in the predictive power of the model (R^2 change=7%; p<0.001), the inclusion of the distribution of pedestrians and Choice measures adds a modest increase of 5-4% (p<0.001) respectively. The signs of urban design quality attributes are consistent with a priori expectations; the frequency of selected segments increases with increased proportions of active uses along the route, higher quality of sidewalk maintenance, the presence of street names.

From the configurational measures only global Choice entered the model as a significant variable (positive and statistically significant at a 99% level of confidence). This implies that street segments which serve as bridges between all routes within school-environments are clearly associated with navigation behaviour. To account for the low and non-significant effect-levels of configurational measures, values were compared across the study areas. The Student's T-test was used for comparing the average Metric Reach (1600m) values between school-environments.

The results clearly demonstrate the variations between street network connectivity patterns within the study areas (Figure 5). However; when the total set of selected routes per school is mapped on the street networks within buffers analysed according to Metric Reach, it becomes clear that there is incongruence between the distribution of routes selected and the configuration of street layouts. As shown in Figure 6, since the spatial structure of street networks is unevenly distributed within the buffers, route selection is less tuned to the spatial structure of streets and is affected more by other factors. This suggests that increased average connectivity levels of the street network within catchment areas of schools do not suffice in fostering children's route selection behaviour. The uniform distribution of connectivity patterns is a critical factor that needs to be considered in designing neighbourhoods that supports walking.

	R^2	β	AIC	*p* value
schools	0,12	-0,37	842,90	0,00
Distance[a]	0,23	0.01	798,49	0,00
Pedestrians	0,28	0,10	773,69	0,00
Choice (n)	0,32	0.00	761,86	0,01
Signs (yes)	0,33	0,06	760,18	0,05
Active uses	0,34	0,25	756,79	0,06
Setback distance	0,35	0.00	756,47	0,12
Sidewalk maintenance	0,35	0,07	756,87	0,19
Landmarks (yes)	0,35	0,13	757,59	0,23
Sidewalk width	0,35	0.00	758,61	0,29
Street wall	0,35	0,05	759,88	0,34
Traffic signals (yes)	0,36	0,07	761,42	0,42
Street trees (yes)	0,36	0,03	763,26	0,54
Speed limit	0,36	0,01	767,20	0,57
Metric Reach	0,36	-0,01	769,89	0,22
Building height	0,36	-0,01	773,65	0,72
Crosswalks	0,36	0,02	775,88	0,76
Recreation	0,36	-1,18	778,18	0,85
Retail	0,36	0.04	780,54	0.95
Directional Reach	0,36	0.00	782,91	0,96
N	400			

[a] straight-line distance between the midpoint of each audited segment and the related school.

Table 2. Parametre estimates for the stepwise regression model estimating the frequency selected road segments for all used paths considered as a single set.

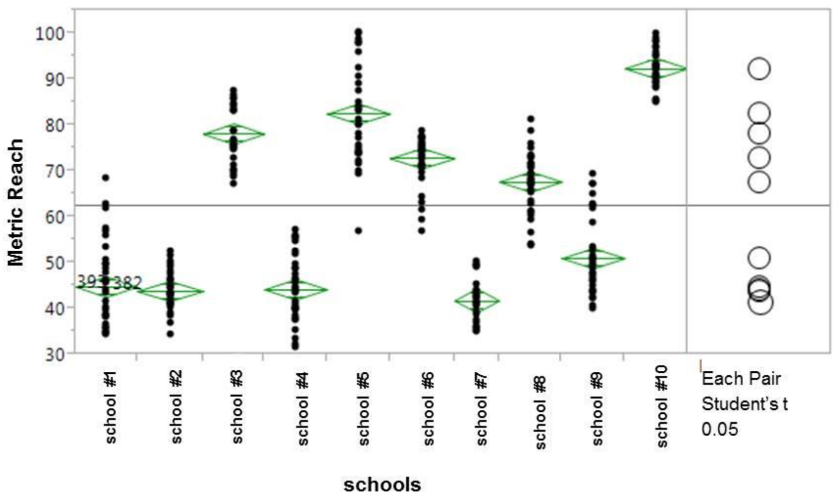

Figure 5. Variations in Metric Reach (1600m) between schools (N=400; r^2: 0.87; p<0.001).

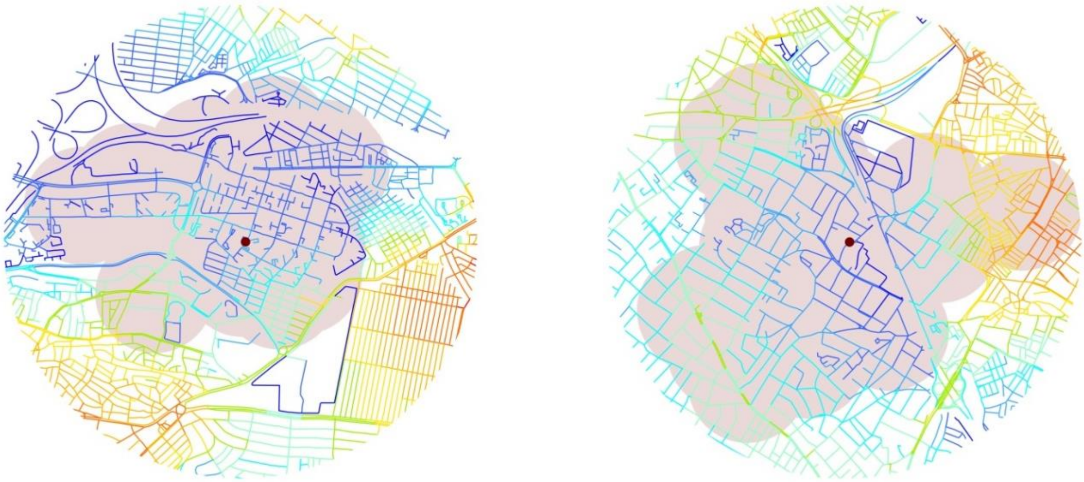

Figure 6. Street network layout captured within 1600 metre radius of two schools. Streets are coloured according to Metric Reach (1600m), red to dark blue representing higher to lower values respectively. The shading shows the distribution of home-environments of surveyed students who walk to/from school.

4. Conclusions and implications

Present results extend previous findings of environmental correlates route selection behaviour by using measures that attempt to objectively measure the perceived and seemingly subjective qualities of the street environment as well as cognitive qualities of the street layout (structural characteristics of the street network shown to impact the cognitive effort required to navigate through an area). These initial findings demonstrate that route selection is a complex cognitive process, with influences embedded within both the perceptual and objective environmental features. Hence, considering multiple aspects of the urban environment are important in designing for walkability.

Having homes within walking distance of schools, thus shortening the distance of routes, as well as the presence of pedestrians along the routes emerged as the most significant correlates of route selection. These are consistent with earlier studies which report that creating neighbourhoods in which residential destinations are within walking distance of homes (Cervero, 2002), and designing streets to attract more pedestrian flows (Kubat et al., 2012) are critical in affecting navigation choices. In addition, higher levels of active land-uses opening onto the streets appeared to have associations with the frequency of selected segments. 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 behaviour (Cervero, 2002; Lee et al., 2013).

More importantly, this study emphasizes the significance of spatial structure of street network in affecting navigation choices. Configurational variable global Choice explained a significant amount of variance in the frequency of selected segments controlling for urban design attributes and physical features. This result suggests that navigation choices are more related with the *through* movement potential of street segments rather than the potentiality based on *to* movement or metric distance. From a theoretical point of view, this implies that urban navigation strategies in targeted-walking are more related to the topo-geometric properties of the street network rather than the metric or geometric properties alone. From a design policy point of view, designing better connected street networks with reduced directional distance between home and school might serve as inducement for navigation choices and walking behaviour.

In addition, the results of the multivariate regression models point to the importance of school-environment at 1600 metre radius in affecting children's walking behaviour between home and school. This is in contrast with the findings of previous studies relating to US riders and the conventional wisdom among planners which suggests 400 to 800 metres as walking distance threshold (Untermann, 1984). Hence; direct and dense connections between activities (i.e. between residential and retail uses) and a connected street network with more direct connections between origin-destination nodes distributed evenly within 1600 metre of the school may influence children's travel behaviour and support walking as a mode of transport between home and school.

The weaker associations between urban design qualities and route selection may be due to the limited sample size and the characteristics of selected areas. Due to limited resources only 40 street segments (with an average of 118m) were audited from each school-environment. This limitation likely resulted in underestimated effect levels of urban design qualities. Increasing the sample size could strengthen the study, but the homogeneity of street environment characteristics within individual study areas were considered to justify the validity of the study design. The results of analyses showed that multivariate regression models produced low coefficients of determinations, indicating that urban environment is a necessary but not sufficient component in explaining route selection process. Arguably more extensive street-level surveys could increase the predictive power of the models, but the main aim of this study was to primarily examine the comparative significance of various environmental attributes and variables derived from connectivity networks, not so much to develop the best model. School-environment was defined as the area within 1600 metre walkable buffers around the schools, but some students reported walking longer distances. Hence, future research should consider higher threshold distances to examine the link between urban navigation and street environment. Moreover, the explicit consideration of children's perceptions about the built environment is also important since past research has shown that children's assessments of environmental barriers to walking may differ from those of the adults (Timperio et al., 2004).

Nevertheless, the descriptive information provided by this study broadens our understanding of the environmental attributes associated with children's navigation choices in target-directed walking. Findings augment the knowledge-base that supports urban navigation by emphasizing the contribution of the spatial structure of the street network, over and above the impacts of urban design qualities and physical features of the street environment. Based on the preliminary evidence presented here, the further elaboration of this study may supplement the existing literature on the environmental correlates of children's walking behaviour. This study will be strengthened through more extensive assessments including but not limited to the increasing the sample size, the expansion of the database on street-level pedestrian quality attributes, such as the presence of slopes and sight lines, and the consideration of children's assessments of the built environment. As the database and analyses expand, it might be possible to throw more light on the associations of street-level urban design qualities, physical features of the street environment, and street network configuration with children's route selection for purposeful kind of movement directed towards distinct destinations.

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