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THE EFFECT OF BUILT SPACE ON WAYFINDING IN URBAN ENVIRONMENTS: a study of the historical peninsula in Istanbul

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Abstract

This paper reconsiders the question of how the built environment, in terms of the spatial configuration of urban layout and land-use patterns, affects wayfinding performance. In an attempt to develop physical design solutions, first-time visitors' directed search patterns within a 2x2km area in the historical peninsula of Sultanahmet, İstanbul, are recorded. The recorded data are analyzed to determine the extent to which street connectivity, measured by metric and directional reach, and visibility patterns, measured by visual integration, visual connectivity and visual clustering coefficient, are related to spatial learning –path selection for exploratory movement. This study enhances previous findings using space syntax by better controlling for the effects of land-use as compared to the effects of spatial configuration of urban networks. Asserting the independent role of configurational design is important given that urban morphology acts as the long term framework within which land-uses change over time. The findings imply that the overall spatial configuration of urban layouts –both at the local and global level– may prove to be an important variable for the description and modulation of human spatial behavior in urban environments.

WAYFINDING BEHAVIOR IN URBAN SETTINGS

This paper reconsiders the question of how the built environment, in terms of the spatial configuration of urban layout and land-use patterns, affects wayfinding performance. This study is part of a larger research agenda supported by Istanbul Metropolitan Municipality, whose primary aim is to enhance the spatial and visual organization of Istanbul's historic core by evolving a spatial regeneration strategy from the perspective of the pedestrian. This study builds on the question asked by Golledge: "How do variations in the environment itself influence the cue selection and the storage of environmental information?" (Golledge 1987). The question asked here is whether the configuration of urban space influences the patterns of exploration in an urban environment, over and above the influence that may be exerted by development densities.

There is a considerable body of literature on wayfinding behavior and strategies humans perform when orienting themselves and navigating through space. A wide range of disciplines including but not limited to environmental psychology, architecture, geography, city planning, and cognitive science has investigated the ways in which people understand, represent and move around the built environment. In most of the literature, wayfinding performance is analyzed either according to self-report (Weisman 1981), sketch map drawings (Lynch 1960; Tversky 1981) , verbal route directions (Couclelis 1996; Lovelace et al. 1999) or the ability to point to non-visible land-marks (Montello 1991; Haq and Zimring 2001) and/or locate places on a plan of the premises (Evans et al. 1984; Moeser 1988). Direct observation of wayfinding, particularly in large-scale spaces such as urban systems, is rare. The common difficulty within these disciplines is finding ways to describe and quantify the configurational variables of the physical environment in a systematic way. Sketch maps produced by urban navigators reveal useful data on the ways in which the relational properties of space is cognized by humans, but they lack consistent descriptions of environment to be tested against.

In an attempt to quantify the built environment, most of the related literature has addressed two dimensions of urban form: *accessibility* and *visibility* patterns of spatial layouts. Theories regarding how the accessibility patterns of urban networks affect wayfinding behavior have mainly focused on two aspects of urban structure: metric distance (total path length) and directional distance (number of turns along the path). Studies on spatial cognition indicate that response time of individuals mentally solving visual mazes with orthogonal paths increases as a linear function of the total path length and the number of turns along it, but within the overall regression models, the number of turns appears to be the most important explanatory variable (Crowe et al. 2000). Similar research carried out in the field of environment and behavior studies by analyzing sketch maps demonstrate that route directness plays a significant role in the response time and accuracy of direction by affecting the estimation of metric route length (Lee 1973; Sadalla and Magel 1980). Besides their effects on distance estimations, direction changes have been confirmed to have significant impact on cognitive effort during navigation. Researchers analyzing mental representations of individuals have argued for systematic distortions of non-orthogonal street intersections towards right angles and "smoothing" curves into straight lines (Griffin 1948; Lynch 1960; Tversky 1981; Golledge 1992). Furthermore, there is further evidence that increased number of direction changes reduce the accuracy of orientation and spatial cognition (Christenfeld 1995; Bailenson et al. 1998). Hence, studies on spatial cognition within varied disciplines underline the importance of topological relations in understanding and navigating through built structure. It is argued that people's spatial cognition progresses from topological to positional and finally to metric cognition (Appleyard 1970).

Since understanding the layout of a city involves operationalizing the sequence of views created with one's movement in the environment, researchers have developed a set of analytical measures to quantify the

visual dimensions of spatial environments. Gibson's (1979) conception of ecological visual perception; Giedion's (1971) classification of architectural types; 'intervisibility' developed in computer topographic models (Gallagher 1972); isovists (Tandy 1967; Benedikt 1979) and viewsheds (Amidon and Elsner 1968; Lynch 1976; Burrough 1986) in the fields of landscape architecture and planning; 'all lines map' (Peponis 1997), and visibility graph analysis (Turner and Penn 1999; Turner et. al. 2001) for the analysis of urban and building spaces have been developed for the assessment of visual properties of the built environment. Using these measures, studies on wayfinding research have found that the visual dimension of built space has a strong influence on the way people move around in such complex built environments. Benedikt and Burnham (1985) showed how perception of space is affected by various isovist attributes. HMSO (1994) and Peatross (1997) used isovists as a way of classifying observations of behavior to identify crime locations and control points. Analyzing housing estates in Athens Trova et al. (1999) revealed that the density of presence is powerfully correlated with the properties of visual fields measured through isovist fields. Peponis et al. (1997) explored convex partitions to describe movement as a pattern of discrete transitions from one space to another. Turner et al. (2001) used visibility graph analysis to show the correlation between the local and global dimensions of visibility and the movement patterns of visitors in the Tate Gallery. However; since visual perception is relatively a local spatial property compared to the overall pattern of street connections within the entire urban network, navigation through any complex environment requires a multilayered description of the spatial structure.

Building on the existing literature, the theoretical question that this paper deals with is: How do connectivity patterns, visual fields, and land-use compositions interact to anticipate patterns of wayfinding behavior? In exploring this question we concentrate on a syntactic analysis of directed search performance where success depends on an understanding of configurational properties rather than solely relying on landmarks, signage, or other cues. Concentrating on an experiment in a real-world setting, this study might offer richer clarifications to the relationship between wayfinding behavior and different measures of urban form – namely spatial configuration of urban layout and land-use compositions.

MEASURES AND TECHNIQUES

The study investigates mainly the accessibility and visibility properties of urban layouts but also aims to unveil the significance of local urban design parameters in shaping the patterns of wayfinding behavior. To this end, the basis of our analysis in this research is street connectivity and visibility patterns as a function of network configuration. Thus, we chose to describe the configurational properties of the urban space with regard to both visual and physical accessibility to determine the extent to which spatial patterns affect navigational performance.

Segment-based Measures of Connectivity

Segment-based connectivity measures applied in this research (Peponis et al., 2008) offer a systematic framework through which to evaluate the urban fabric in terms of its potentiality (density of streets) and structure (directional bias based on configuration). The analysis is based on standard segment-based representations of street networks according to street center-lines. The unit of analysis is the road segment. Road segments extend between choice nodes, or street intersections at which movement can proceed in two or more alternative directions. Road segments may contain one or more line segments. A line segment

is the basic unit of the map drawn and is always defined as a single straight line. Thus, the analysis treats the unit of analysis (the road segment, for which the individual values are computed) and the unit of computation (the line segment which provides the base metric for values) as different entities. Figure 1 illustrates the new unit of analysis by clarifying the difference between road segments and line segments.

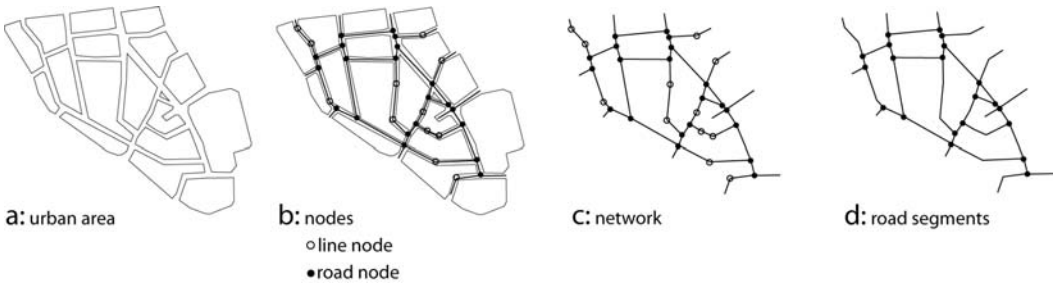


Figure 1. Definition of line segments and road segments. Source: Peponis et al. 2008.

Metric reach captures the density of streets and street connections accessible from each individual road segment. This is measured by the total street length accessible from each road segment moving in all possible directions up to a parametrically specified metric distance threshold. *Directional reach* measures the extent to which the entire street network is accessible with few direction changes. This is measured by the street length which is accessible from each road segment without changing more than a parametrically specified number of directions. While metric reach extends uniformly along the streets surrounding a given road segment, directional reach may extend much less uniformly, because it is sensitive to the shape and alignment of streets, not merely to their density. The connectivity measures used in this paper are inherently parametric, in that one can vary what rotation angle counts as a direction change or what walking threshold is used to measure the catchment area associated with each individual road segment. Figure 2 illustrates the two measures. The decision to include these measures bears on the relationship between urban planning and urban design. Urban planning is oriented towards principles of general applicability and tends to be concerned with the average or aggregate properties of areas. Urban design must, by definition, address the fine grain of specific contexts. It is concerned with the internal structure of areas and with the way in which street layout impacts the nature, orientation and performance of building developments for which it provides the context. Walking is, after all, a pre-eminently context-dependent activity and one which occurs according to the fine grain of environment as well as according to its larger scale structure. That is why appropriately discriminating measures of street connectivity are essential to better design for walkability.

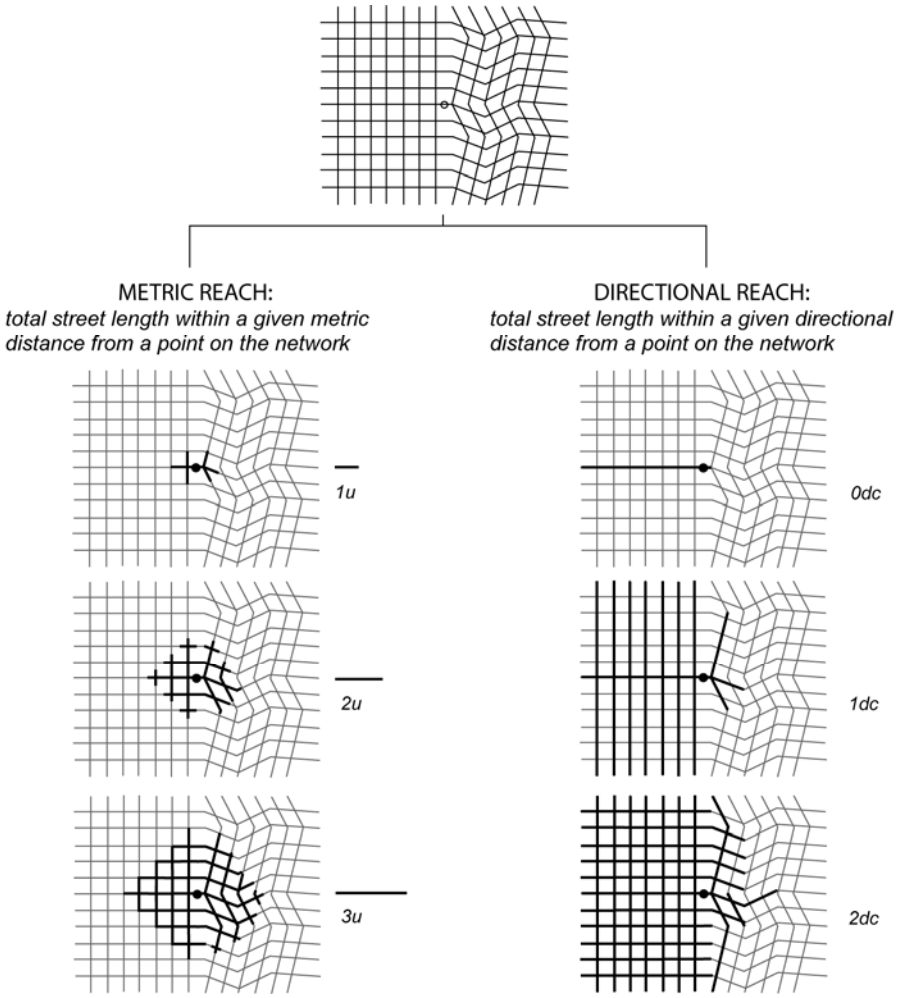


Figure 2. Diagrammatic definition of segment-based connectivity measures. Source: Peponis et al. 2008.

VGA

A visibility graph analysis (VGA) identifies the extent to which locations are mutually visible in a spatial network. Two nodes are connected if the corresponding locations are mutually visible. In the case of no mutual visibility, the analysis calculates the number of nodes needed to cross for a specific location to be visible by others in the system. VGA is derived from the concept of 'isovists', which was first introduced in spatial analysis by Tandy (1967) and later developed by Benedikt (1979) and Braaksma and Cook (1980) for quantitative analysis of spatial environments. Despite the fact that isovists are sensitive to the shape of spaces, the sensitivity to shape is dependent upon the configuration of space within which it is possible to move and occupy positions (Peponis et al. 1998). Isovists are of interest to spatial analysis, because they offer a systematic framework of addressing the relationship between the navigator and her immediate spatial environment (Turner and Penn 1999).

The visibility graph was formed by taking a 1.0 m grid of vertices covering all accessible spaces in the study area, taken at eye height, to capture meaningful features of the environment related to spatial accessibility. Depth Map (Turner 2004) was used for the VGA. In order to study a large urban complex such as the

Sultanahmet district, one global measure ,*visual integration (HH)*, and two local measures, *visual connectivity* and *visual clustering coefficient (Ci)*, were used. *Visual integration* is theoretically similar to global integration (Hillier 1984) and describes the relative visibility of a point to all others within the system. The measure is important in spatial analysis, because it has been found to correlate with occupancy rates in buildings and pedestrian movement distributions in urban space (Batty and Conroy 1998; Turner and Penn 1999; Desyllas and Duxbury 2001; Turner 2001). Intuitively, integration reflects the centrality of a node with respect to the whole graph. *Visual connectivity* is a local measure which captures the amount of space directly visible from each node, and thus approximates isovist area (Conroy 2001). A *clustering coefficient* is defined as the proportion of nodes which are actually connected within the isovist to the number of maximum connections; thus, it reveals the intervisible space within the visibility neighborhood of a point (Watts and Strogatz 1998; Turner et al. 2001). It measures the degree of convexity or multidirectionality of the isovists generated from a specific location. Its value varies from 0 ('spikiness' of isovist) to 1 (convexity of isovist). Clustering coefficient detects how visual information varies as one navigates the system; hence, it seems an important spatial indicator of the potential copresence in networks and therefore the potential to interact (Turner et al. 2001).

Land-use Compositions

Parcel-based data were categorized into residential and non-residential (office, retail, institution, recreation, industrial) for the purpose of distinguishing between the effects of each on the distribution of movement. Gross densities of land use were calculated as a linear measure at the 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 demonstrates the way in which development densities were associated with street segments.

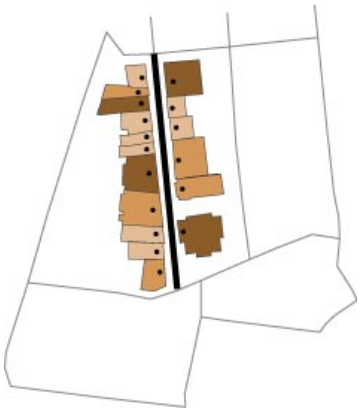


Figure 3. Gross densities of buildings that open onto the individual road segment were calculated for each segment covered in each route.

THE STUDY AREA

Sultanahmet district, the heart of historic old Istanbul and a popular sightseeing area, was chosen as the study area (Figure 4). Embedded within a rich cultural and historical heritage, the historical peninsula of Sultanahmet includes monuments, examples of civil architecture, and archeological remains. The spatial layout of the area is comprised of two separate layers: the retail-led live centre including the prominent historic landmarks and the seaside Promenades on the Northern and Southern sides serving as entry points opening onto the centre. The main spine and the dominant axis of the old city which survived through the Byzantine (namely Mese) to Ottoman (Divan yolu) and which is still present today (as Ordu street) has been referred as the "High Street" in this paper. The High Street, along which the tramline runs, crosses the historic core on the east-west axis, linking the heart of the centre with the surrounding neighborhoods. The area, which is officially registered as a 'Conservation Site', has been exposed to an intense vehicle and pedestrian demand that led to its degeneration. In spite of the recent attempts by Istanbul Metropolitan Municipality to encourage walking through the provision of pedestrianizing certain streets and remodeling sidewalks, the touristic area seems to generate a number of wayfinding problems.

First, in spite of the proximity of the historic core to the seaside Promenades, visual connection between the two is weak due to reduced visual permeability. Since the two zones are isolated from each other, they fail to form a unified city center. Second, although glimpses of the landmarks situated at the historic heart can be seen from the waterfront, multilevel parking ramps along the northern Promenade and the elevated railway tracks along the southern Promenade hinder urban legibility. These uninviting views lack in appeal for visitors to enter into the neighborhood behind. Consequently, seaside Promenades fail to operate at levels required for a thriving gate to the historic centre. Third, there is a major imbalance between the two main entrance points to the area: while the levels of pedestrian movement and space use are very high along the Northern seaside Promenade due to the existing tramline and the pier, the flow of movement drops significantly at the Southern Promenade, partly because of the visual and physical disconnection, and partly because of the paucity of transportation options available on the southern side. This imbalance causes insuperable congestion problems on the northern corner of the peninsula. Fourth, the adjacent intersecting streets are disconnected from the High Street both spatially and visually. Hence, pedestrian activity is distributed along this linear axis, failing to penetrate into the adjacent spaces. Low levels of pedestrian densities within the surrounding areas both lead to unsafe urban spaces by weakening the 'natural surveillance' of these spaces and consign historic structures present within these areas to oblivion. All of these potential problems are augmented by an inconsistent and insufficient signage system.

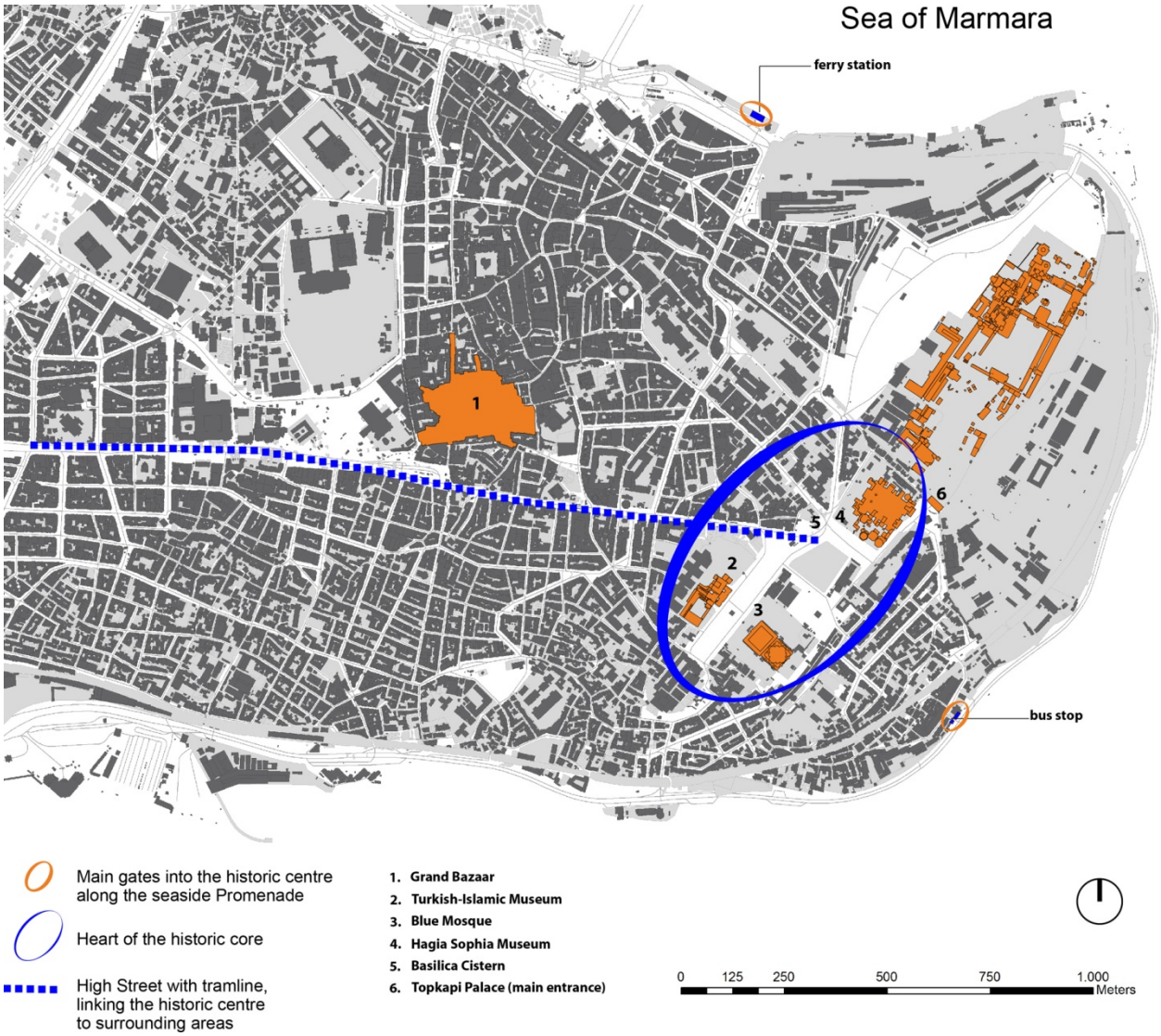


Figure 4. Study area showing Sultanahmet district. Large rectangle denotes the heart of the historic core; two smaller squares mark the main gates along the seaside Promenades; the dotted line shows the High Street. Structures in orange demote the destination points along the route; those in blue mark two different origins for two different groups.

WAYFINDING DATA COLLECTION

In an attempt to understand how urban spatial configuration affects wayfinding performance, visitors' directed search patterns within a 2-by-2km area in the historic area of Istanbul were recorded. The recorded data were analyzed to determine the extent to which street connectivity, measured by metric and directional reach, and visibility patterns, measured by visual integration, visual connectivity, and visual clustering coefficient, are related to spatial learning –path selection for exploratory movement. Eleven undergraduate architecture students without any prior familiarity with the urban context were asked to conduct directed searches for specific locations. The exercise was carried out on weekends, when the

density of pedestrians is highest. Students were asked to navigate in the area between six predetermined landmarks. These specific locations are the most frequently visited locations by tourists and the main historical sites included in guided walking tours. More particularly, subjects were divided into two groups with different starting points. The first group, including six students, started from the pier located on the Northern Promenade; the latter, including five students, started from the bus stop located along the Southern Promenade. The end point, in this case the ferry station at the pier, is the same for both groups. Figure 4 indicates the locations of the starting points for each group and the specific landmarks selected for the directed search. Different subjects were asked to conduct different path combinations so that each of the six landmarks acted as both origin and destination from the other five locations.

Before performing the search tasks, subjects were shown an abstract map –including the exact locations of multiple landmarks as reference points but excluding any street network– to familiarize themselves with the area. During the search subjects were asked to carry a data-logger GPS device that recorded their tracks. The data collection interval was set at 0.01km. to minimalise the location positioning error. Subjects were instructed to read signage available but not to ask any questions during their search. At the end of their search subjects were interviewed with regard to their wayfinding behaviors. Figure 5 shows the typical wayfinding routes that belong to group 1 and group 2, respectively. The direction of almost all six routes in group 1 is in an anticlockwise direction with a larger loop at the northern/beginning part and a rather linear track along the historic heart. The direction of the tour route in group 2 is linear due to the nature of the wayfinding task. For all the subjects, the average distance and time travelled were 5100m and 1.30 hours, respectively.

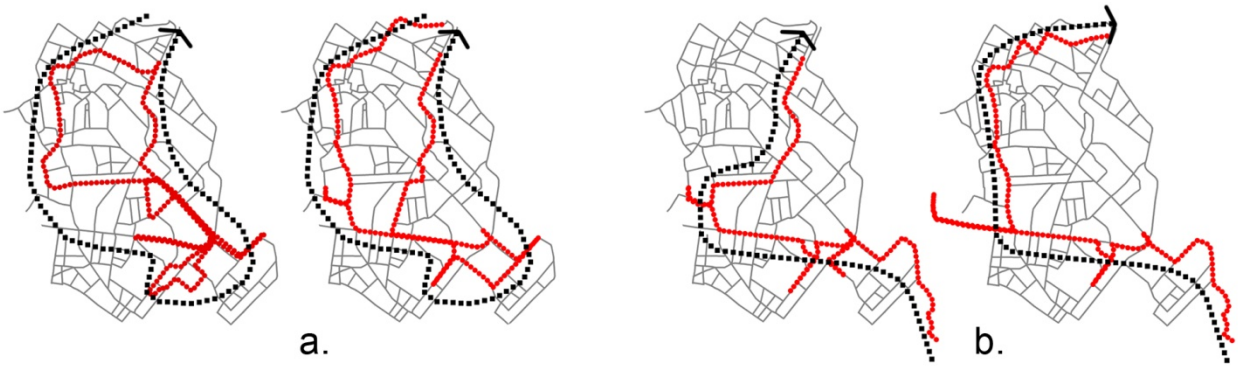


Figure 5. Typical wayfinding routes in (a) route 1 and (b) route 2.

SPATIAL ANALYSIS OF THE STUDY AREA

In order to reveal the visibility patterns of the Sultanahmet district as a function of its spatial configuration, a visibility graph of the area was constructed by using the Depthmap software. The accessibility pattern of the area was evaluated by analyzing its street connectivity using a GIS-based software developed by Zhang at Georgia Tech.

Connectivity pattern of the area

In this research metric reach was computed for 1, 0.5 and 0.25 mile walking distance thresholds. Directional reach was computed for 0 and 2 direction changes subject to a 10° angle threshold. The underlying reason in the selection of 10° as the threshold parameter was to make the analysis more sensitive to the distinction between linear and curvilinear systems. The choice is also consistent with literature suggesting that turns that vary minimally (between 10° and 15°) from an axis orthogonal to the direction of travel are the least disorienting (Montello 1991; Sadalla and Montello 1989).Thus, each street segment is associated with five primary connectivity measures: metric reach for 1 mile, 0.5 mile and 0.25 mile walking ranges; and directional reach for 0 and 2 direction changes. The measures of metric and directional reach not only help compare one area with another, on average, but they also help discriminate between proximate road segments within the same area. Figure 6 shows the street networks of the study area embedded within the surrounding 3-by-3km grid, coded according to 0-directional reach. Even in the absence of any other design information, such as street width, a hierarchy of streets emerges based on the intrinsic relational properties of the networks. As illustrated in Figure 6, in the directional accessibility model the High Street carrying the tramline along the east-west axis, side-streets intersecting the High Street at perpendicular angle, and the diagonal street connecting the Sultanahmet Square with the Cistern Basilica are picked up.



Figure 6. Street networks captured within the study area. Streets are color-coded at the same scale according to 0-directional reach (10o). Dark colors reflect higher values, while light colors show lower values. Thus, colors are based on the ordering of individual streets within the entire street network according to their differentiation of internal spatial structures.

Visibility pattern of the area

The visibility graph was constructed for all nodes specified on an evenly spaced grid of 0.1m, covering all publicly visible and accessible spaces. After creating the graph, integration, connectivity and clustering coefficient values were calculated at each point. Figure 7a shows the pattern of visual connectivity pattern

of the study area. Red indicates visually most connected while blue shows visually least connected spaces from all other nodes. The historic core of the district and the part of the High Street that is closest to the core are favored by visual connectivity. Pedestrian spaces between the Blue Mosque and Hagia Sophia are picked up as the main focus in the area. Spaces opening to the Northern Promenade as well as the diagonal street connecting the northern corner of the peninsula to the historic core appear to have better visual connectivity compared to the surrounding network. The pattern of clustering coefficient (Figure 7b) clearly delineates areas of informational stability. Streets in close proximity to the heart of the historic core and the High Street are highly clustered (red for higher value through to blue for lower value) whereas Sultanahmet square, the High Street and the spaces along diagonal and northern streets linking the pier with the core offer multidirectional fields of view, suggesting a space system with potential for possible copresence and interaction. As we move through the transitional spaces surrounding the historic core towards the neighboring areas, spaces become gradually more clustered.

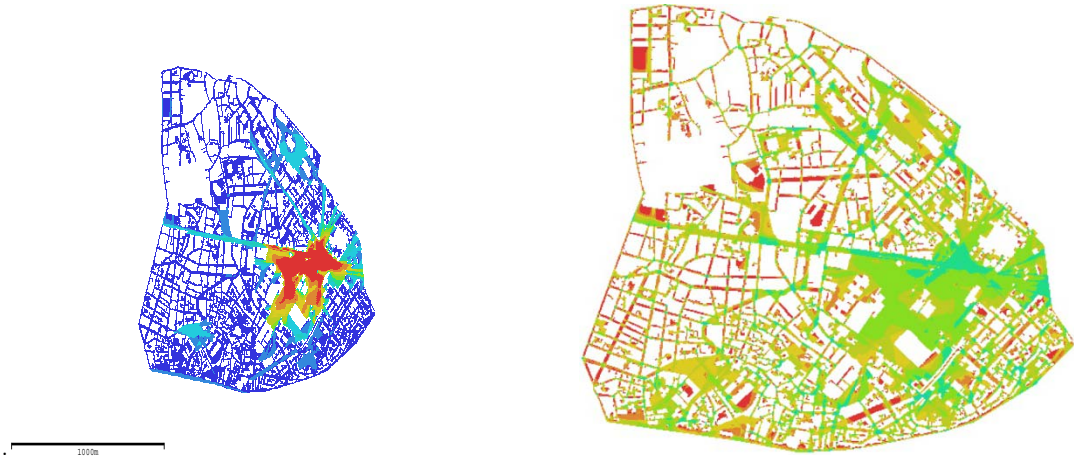


Figure 7. Visibility graph analysis of Sultanahmet district showing (a) visual connectivity pattern, and (b) visual clustering coefficient.

SPATIAL LAYOUT AS THE DETERMINANT OF WAYFINDING BEHAVIOR

In order to reveal the pattern of wayfinding as a function of spatial layout, each traced path was transcribed as a set of selected road segments and the total frequency of use of each road segment was calculated. Observing the search patterns in relation to the patterns of visual integration pattern of the area, there appears to be a qualitative correspondence between the two. Red indicates visually most integrated whereas blue shows visually least integrated spaces from all other nodes. The visual integration model (Figure 8a) shows the central square at the core of the area and the High Street as the most integrated area of the district with a secondary integration core surrounding the central core, combined with a series of shorter axes. The overall search pattern (Figure 8b) demonstrates that visitor distribution is strongly biased towards the central spaces at the core of the district. They then tend to move along the central axis of the area along the High Street and along a series of shorter cross axes –the diagonal and the northern streets

linking the core to the pier. This indicates that analyzing the comparing the movement patterns as a function of configurational variables may prove fruitful in understanding wayfinding behavior in Sultanahmet area.



a. b.

Figure 8. (a) Visual integration pattern of Sultanahmet district, and (b) routes of wayfinders during their search in the area considered as a single set.

To carry out quantitative analysis, the average integration, connectivity, and clustering coefficient values for each road segment were calculated. As such, the VGA attributes of each road segment are the average of the VGA attributes of all the points that comprise a 10m. wide buffer around the individual street centre-line. Having obtained the values for the gates, the VGA measures and street connectivity measures of road segments were then plotted against the total frequency of segment selection in order to compare the explanatory power of visibility and accessibility measures and check for colinearity between measures. When bivariate regression equations were estimated for metric reach for 1, 0.5, and 0.25 mile ranges and directional reach for 0 and 2 direction changes separately, the highest coefficient of determination (*r2*) was obtained for 1 mile range and 0 direction changes. As a result, the coefficients of linear models computed with metric reach (1 mile) and 0-directional change are reported here.

Results of bivariate regressions (Table 1) between the frequency of use of road segments and configurational variables reveal a considerable effect of urban layout on directed search performance. All spatial measures, except for Reach (1mile), are significantly associated (at a 99% level of confidence) with the frequency of use of road segments. Comparisons of coefficients of determination indicate that average visual connectivity has the highest explanatory power. While walking shares are positively correlated with 0-directional Reach (10°), average visual integration and average visual connectivity, the coefficient for average clustering coefficient (*Ci*) is negative. This supports the findings of various studies reviewed above which suggest that clustering coefficient is highly related to the decision-making process in wayfinding since

navigation within complex environments involves making decisions about prioritizing certain cues available through one's visual information.

Table 1. Results of bivariate regressions between the configurational variables and the frequency of use of road segments.

Correlations		Reach (1 mile)	0-Directional Reach (100)	avg. connectivity	avg. Ci	avg. HH	segment-use frequency
Reach (1 mile)	Pearson Correlation	**1**	**0,022**	**-0,295**	**0,157**	**-0,292**	**0,033**
	Sig. (2-tailed)		0,753	0,000	0,026	0,000	0,648
	N=200						
0-Directional Reach (100)	Pearson Correlation	**0,022**	**1**	**0,163**	**-0,040**	**0,426**	**0,362**
	Sig. (2-tailed)	0,753		0,021	0,575	0,000	0,000
	N=200						
avg. connectivity	Pearson Correlation	**-0,295**	**0,163**	**1**	**-0,432**	**0,696**	**0,505**
	Sig. (2-tailed)	0,000	0,021		0,000	0,000	0,000
	N=200						
avg. Ci	Pearson Correlation	**0,157**	**-0,040**	**-0,432**	**1**	**-0,436**	**-0,272**
	Sig. (2-tailed)	0,026	0,575	0,000		0,000	0,000
	N=200						
avg. HH	Pearson Correlation	**-0,292**	**0,426**	**0,696**	**-0,436**	**1**	**0,386**
	Sig. (2-tailed)	0,000	0,000	0,000	0,000		0,000
	N=200	200	200	200	200	200	200
frequency of use of segment	Pearson Correlation	**0,033**	**0,362**	**0,505**	**-0,272**	**0,386**	**1**
	Sig. (2-tailed)	0,648	0,000	0,000	0,000	0,000	
	N=200						

From these initial findings, it is hypothesized that, wayfinding behavior in urban areas are influenced by the multiple-interacting urban form features, such as the visibility and accessibility of spatial layout and land-use compositions. This suggests the need to take multiple-interacting effects of these urban design variables into account when modeling wayfinding performance. Consequently, we produced multivariate regression models for the frequency of use of road segments to identify the statistical significance levels of all variables and to capture the unique contributions of configurational variables to the overall model. Table 2 summarizes the results of regression models including visual analysis variables, street connectivity measures, and land-use compositions. Each column shows, first, the predictability of the model with only the visibility properties, and then, in turn, the effect of adding the connectivity measures, and land-use measures to the model. The results of multivariate models demonstrate the effect of visibility and accessibility on space use. Indeed, 38% of space occupancy can be explained by the spatial structure of the urban environment, that is, the highest levels of visitors' movement were observed in visually most connected areas and in street networks with more direct connections. When the model is examined, the highest standardized coefficient is obtained for average visual connectivity is found to be the strongest

determinant of search patterns. Average clustering coefficient barely enters the model as a statistically significant variable (p<0.10). Adding accessibility measures, metric reach (1 mile) and 0-directional reach (10o), increases the explanatory power of the model moderately (R2 change=12%; p<0.01). However; among the accessibility measures 0-directional reach (10o) has a higher significance level than street network density. Somewhat surprisingly, land-use variables, residential and non-residential square meters per 100m, do not enter the model as statistically significant variables. It can be speculated that since the study area includes a rather homogenous land-use composition, wherein non-residential use dominates, it fails to capture the variations in route selections. This suggests that land-use variables might have a stronger influence on wayfinding behavior in areas with increased spatial inter-mixing among development densities.

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

	Visibility measures			+ Accessibility measures			+ Land-use measures		
	B	*t*	*std β*	*B*	*t*	*std β*	*B*	*t*	*std β*
constant	–	1.48	–	–	0.68	–	–	0.72	–
avg. HH	0.16	0.59	0.052	-0.39	-1.37	-0.13	-0.42	-1.48	-0.14
avg. Ci	-1.74	-0.83	-0.06	-3.17	-1.63	-0.11	-3.22†	-1.65†	-0.11†
avg. connectivity	**0.00**	**5.08**	**0.44**	**0.00**	**6.60**	**0.54**	**0.00**	**6.21**	**0.53**
Reach (1mile)	–	–	–	*0.05*	*2.73*	*0.17*	0.06*	2.53*	0.18*
0-Directional Reach (10o)	–	–	–	**8.21**	**4.88**	**0.32**	**8.18**	**4.86**	**0.32**
residential m2 /100m	–	–	–	–	–	–	-0.00	-0.33	-0.02
non-residential m2 /100m	–	–	–	–	–	–	-0.00	-1.29	-0.08
N=200									
R2	**0.26**			**0.38**			**0.38**		
R2 adjusted	**0.25**			**0.36**			**0.36**		

Note: Numbers in bold= significant difference (p<0.01); * significant difference (p < 0.05); † statistical trend (p < 0.10).

The multivariate regression model proved useful in determining the statistically insignificant variables or those without any contribution to the overall predictability to be omitted in the final model, without leading to biased parameter results. The variables not significant at 10% level were eliminated one at a time to produce a “reduced” model. Figure 9 shows the prediction equations for each variable in the “reduced” model. The signs of variables are consistent with a priori expectations; for example, the frequency of space occupation within an environment increases with higher number of nodes visible from that specific space.

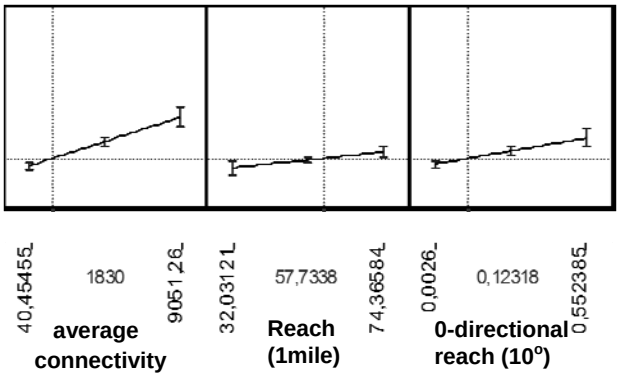


Figure 9. Prediction equations for the variables in "reduced" model.

Table 3 presents the results of effect tests for the model. From the relative effect sizes it is clear that the primary factors in explaining predictability are average visual connectivity and 0-directional reach (10o). While metric reach is statistically significant ($p<0.05$), the relative effect size and significance level of directional accessibility is considerably higher. This finding supports the argument that direction changes are critical to the way in which environments are understood, particularly when walking in unfamiliar surroundings, and that people orient themselves with respect to frames of reference that are as linear as possible (Moeser 1988; O'Neill 1991; Conroy-Dalton 2003). Therefore it would appear that in addition to street density, spatial structure based on directional bias is indeed implicated in the way in which street networks function to support the way people use and understand urban environments.

Table 3. Parameter estimates for "reduced" model estimating the frequency of use of road segments for all used paths considered as a single set.

	Reduced Model		
	B	*t*	*std β*
constant	–	-1.77	–
avg. connectivity	**0.00**	**8.46**	**0.51**
Reach (1mile)	0.06*	2.97*	0.18*
0-Directional Reach (10o)	**7.06**	**4.74**	**0.27**
N=200			
R2	**0.36**		
R2 adjusted	**0.35**		

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

CONCLUDING REMARKS

This study, albeit a work in progress, is a contribution to better understanding the interplay between the visibility patterns–measured through VGA measures–, accessibility patterns –measured through segment-based street connectivity measures–, and parcel-based land-use compositions in the description of visitors' movement patterns in complex built environments. The study outcome is twofold. First; the case study reported here indicates that the spatial configuration of urban layout has significant bearing on visitors as they orientate themselves in, move through and occupy spaces throughout the environment. The observed search and wayfinding paths, as recorded via GPS tools, have been shown to be structured in relation to the patterns of visibility and accessibility of configuration, as assessed through VGA parameters and segment-based street-connectivity measures. The correspondence between the average visual connectivity of network and the space-use frequencies suggests that individuals navigating through urban environment would tend to coalesce in areas of high visual accessibility. Since the inexperienced users do not know the exact location of the target, they need to rely on information available by their surroundings. Thus, we expect inexperienced users to follow the pattern of visual connectivity and spatial accessibility, preferring to travel along road segments with higher values on these measures. Henceforth, we might assume that more direct road segments with higher visual connectivity would lead to a higher congregation of individuals along that space, and, in return, a higher probability of encountering others. It seems that understanding of configurational properties is partially based on retrieval of information on the basis of perceivable evidence –not only local information on spaces seen but also global information cognized on the overall configuration. Although this hypothesis is a simplification of the nature of environmental information storage and cue selection in spatial systems, it shows a clear way in which simple predictive models can be developed with the configurational variables applied in this article.

Second; the findings presented in this article emphasize the importance of including street connectivity in wayfinding studies. Street connectivity was measured using segment-based connectivity measures, metric reach and directional reach. Based on the effect levels and significance levels of both measures, it can be concluded that increasing density of available streets and reducing direction changes within urban areas results in higher levels of pedestrians using the space. However; the results of models 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, in wayfinding behavior. Consistent with theory, route selection is sensitive to the directional accessibility offered by street networks. The fact that direction changes are as important as metric distance in describing street connectivity points to the role of cognitive factors. Navigation choices vary with the degree of familiarity with the environment: novice users are most likely to follow more direct routes with fewer direction changes, irrespective of level changes (Conroy-Dalton 2003; Hochmair and Frank 2002; Hölscher et al. 2006).

These findings regarding urban layout's influence on urban navigation should be evaluated in light of two important wayfinding parameters, namely signage and spatial frames of reference. First, the results of interviews indicate that visitors' wayfinding behavior does not rely exclusively on signs. On the contrary, sign design might cause navigation problems in unfamiliar environments. When asked about factors hindering their search patterns, subjects stated the insufficiency and inconspicuity of signage as the primary factor. The majority of subjects suggested locating information desks in primary nodes and increasing the legibility and presence of signage throughout the area. Second, since the subjects were selected among freshmen without any familiarity with the city, their wayfinding patterns would be quite independent of the relative locations of familiar places in the area. In fact, the majority of students listed environmental cues, such as the mosque minarets, as conducive to wayfinding during their search. Though this viewpoint-dependent

scene recognition does not constitute evidence for the absence of allocentric representations, they would support the fact that visitors' "decision-making" and "decision-executing" processes were not affected mostly by allocentric locations.

Lastly, the limited number of subjects employed in the wayfinding task presented here was a limitation of this study. A logical extension of the work presented in this study would be to include more subjects to validate further or falsify the findings of this research. These caveats notwithstanding, the findings presented in this research support the hypothesis that the overall spatial configuration of urban layouts – both at the local and global level– may prove to be an important variable for the description and modulation of human spatial behavior in urban environments.

In light of these study outcomes, strategic planning and urban design guidelines towards developing proposals for efficient layouts of complex pedestrian spaces. However, important research issues with regard to the overall structure rather than local characteristics of the environment need to be addressed. Focusing exclusively on local features, such as signage and key facilities, and ignoring the ways people occupy and understand configuration would fail to provide adequate wayfinding. As found in this study, notwithstanding the significant and independent effect of configurational parameters on space-use, in the context of similar complex high-density urban environments like Sultanahmet district, urban design features, such as building height profiles and signage, and other urban form dimensions, such as topographical variations and "*choice values*" which can measure through movement potential of each segment, might have significant effects on patterns of movement. Hence, further research is needed to unveil the influence of these urban form and urban design attributes on the extent to which spatial configuration of urban space affects wayfinding behavior.

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