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The Relation Between Urban Morphology and Physical Environmental Qualities: Comparing Walkability in Neighborhoods via Analyses of Spatial Statistics and Indices of Graph Theory and Space Syntax

Ebru CUBUKCU*[1], Bochra MENSI[2], Cigdem HOROZ[3]

[1,2,3]Dokuz Eylul University, Faculty of Architecture, Department of City Regional Planning, Izmir, Turkey

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Urban morphology,
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Abstract: This study aims to compare morphological structure and physical environmental qualities in different neighbourhoods of a small town and investigate whether physical environmental qualities vary by urban morphology. Four neighborhoods were selected in small town Foca, Izmir, Turkey : (A) residential area next to the city center / new development area, (B) residential area at the periophery / new development area, (C) a mixed use area / historical city center, (D) residential area next to the seashore / new development area. First, the spatial statistical analyses were run and indices of Graph Theory and Space Syntax were calculated for each zone to define the morphological characteristics, (the street network characteristics and the dominant urban landuse). Then, the physical environmental qualities that relate to walkability: (1) Proportion of buildings that pedestrians escape, (2) Proportion of parcels that pedestrians escape, (3) Proportion of pop of cafes on the street, and (4) proportion of green areas were measured by spatial statistical analyses. Finally, the relation between morphological characteristics and physical qualities was investigated. The results provide partial support to the main hypothesis (physical environmental quality differs by environmental morphological characteristics). More research are on call to expand the findings for different size of cities.

Kent Morfolojisi ve Mekansal Kalite: Mahallelerde Yürünebilirliğin Mekansal İstatiksel Analizler ve Grafik Teorisi ve Mekan Dizimi Ölçütleri ile Karşılaştırılması

Anahtar Kelimeler
Grafik teorisi,
Mekan dizimi,
Kent morfolojisi,
Yürünebilirlik,
Kentsel desen,
Mekansal kalite

Özet: Bu araştırmanın temel hedefi mekanın morfolojik özellikleri ile mekansal kalite arasında ilişkinin irdelenmesidir. Böylece, farklı morfoljiye sahip kent parçalarında mekansal kalitenin nasıl değiştiği irdelenecektir. İzmir İli, Foça İlçesinde 4 çalışma alanı seçilmiştir; (A) kent merkezine komşu konut alanı / yeni gelişme alanı, (B) kentin çeperinde konut alanı / yeni gelişme alanı, (C) karma kullanım alanı / tarihi kent merkezi, (D) kent çeperinde sahil şeridine komşu konut alanı / yeni gelişme alanı. Çalışma alanı olarak her bölgede Grafik Teorisi ve Mekan dizimi parametreleri hesaplanmış, mekansal istatiksel analizler yapılmış ve çalışma alanlarının sokak dokusu ve baskın arazi kullanımı yönü ile morfolojik sınıfı tanımlanmaya çalışılmıştır. Daha sonra mekanın yürünebilirliği ne ölçüde desteklediğini belirten parametreler üzerinden her bölgede mekansal kalite ölçülmüştür; (1) yayayı korkutan yapıların, (2) yayayı korkutan boşlukların, (3) yayayı çeken yeşil alanların, (4) yayayı çeken ticari birimlerin oranları mekansal istatiksel analiz araçları ile hesaplanmıştır. Son olarak, elde edilen bu veriler ışığında morfolojik özellikler ile mekansal kalite arasında ilişki tartışılmıştır. Elde edilen sonuçlar araştırmanın temel hipotezi olan "mekansal kalite morfolojik sınıflara göre farklılık gösterir" savına destek sunmaktadır. Ancak daha genellenebilir sonuçlar için bu konuda farklı örneklemleri kapsayan daha çok çalışma yapılması gerekir.

* *Corresponding author: ebru.cubukcu@deu.edu.tr*

1. Introduction

All people deserve to live in livable environments that inherit high physical environmental qualities. Given that, planners aim to distribute urban amenities (green areas etc.) over space to guarantee accessibility for everyone. Similarly, administrators aim to provide high physical environmenal qualities for everyone. Yet, both planners and administrators often fail to achieve these ends. Different levels of physical deteriorations are observed in different areas. For example, higher physical deteriorations may be observed in one residential area compared to another. The concentration of physical deteriorations in one area conflicts with the planners' and administartors' main goal of providing equity through out the space. This study aims to investigate the relation between morphological structure and physical environmental qualities. In this study, physical environmental qualities in different neighborhoods of a small town (neighbourhoods with different morphological characteristics) will be compared.

The aspects of urban form can be analyzed via urban morphological analyses. Such analyses can be held for a specific site or for various sites to compare differences at the same time period. Morphological changes at one specific site at different time periods can be traced as well [1]. The studies on urban morphology aim to describe the urban form (or urban fabric) via various types of analyses, including historico-geographical, spatial analytical, configurational, process typology [2,3]. This study would focus on spatial analytical models. These mathematical models [4] often rely on the indices of graph theory and space syntax to quantify the configurational properties of street network. Such analyses has been used for various reasons. For example, Cubukcu [5] used graph theory based indices to compare Turkish, Jewish, Armenian, Frank and Greek neighborhoods in one city to understand how social and cultural features shapes the physical environment. He found that spatial structure of street networks Armenian, Frank and Greek quarters do not differ significantly and the Turkish and the Jewish neighborhoods differ from these three quarters and from each other indicating the influence of religion on the formation of the spatial structure. Kut et al. [6] used graph theory based indices to compare urban pattern in three European capitals, Lisbon, Rome and Sofia to understand the relation between urban pattern and urban history. Canan et al. [7] used graph theory based indices to compare the ten most livable cities in the world and found similarities between them indicating that physical layouts of the cities are clear reflections of their social, economic, and cultural life. Cubukcu and Cubukcu [8] used graph theory based indices to compare urban pattern in informal and formal developments and found that spatial structure of "formal" and "informal" neighborhoods differ significantly. Cubukcu et al. [9] used space syntax indices to measure walkability of street segments and neighborhoods. Kahraman et al. [10] used space syntax indices to compare the physical environmental characteristics around mosques in historical and new development areas. In brief, indices of graph theory and space syntax has been used to understand how social structure shapes the physical environment and vice a versa (how phsyical environment shapes the social structure). Given that, this study first aims to understand the morphological characteristics of four neighborhoods via indices of "Graph Theory" and "Space Syntax". After differentiating the urban forms via morphological analyses; physical environmental qualities in different urban forms would be compared.

Physical environmental qualities could be measured via various parameters. In this study, the objective parameters that relate to "walkability of an environment" would be used. World Health Organization's recent reports have highlighted the fact that (1) the most important health problem of the decade is obesity and overweight and (2) physical environments should be designed to encourage people to walk more. In other words, physical activity is a necessity for a sustainable future. Given that, planners and administrators should provide appropriate physical environmental qualities; which encourage all residents to be physically active. In brief it is assumed that, the physical environmental qualities in a neighborhood is determined by the extent to which a neighborhood encourages residents to walk. Although the relation between walkability and neighbourhood qualities has been studied extensively [11-15], studies rarely focus on urban morphological anayses. Studies highlight that; people tend to walk in areas that involve pop-up cafes and they escape from areas that involve empty buildings, abandoned buildings, commercial areas that are not appropriate for pedestrians (such as auto repair and hardware store) and empty parcels. Given that, this study aims to compare the density of these features in four neighborhoods with different morphological characteristics.

2. Material and Method

Four neighborhoods were selected in a small town (Foca) in İzmir, Turkey (third largest city) to represent (A) residential area next to the city center/ new development area, (B) residential area far from the seashore/ new development area, (C) a mixeduse area/ historical city center, (D) residential area next to the seashore/ new development area. First the spatial statistical analyses, indices of Graph Theory and Space Syntax were held for each zone to define the morphological characteristics. Then, physical environmental qualities (how far the environment supports walkability) were measured. Finally, the relation between morphological characteristics and physical qualities were compared.

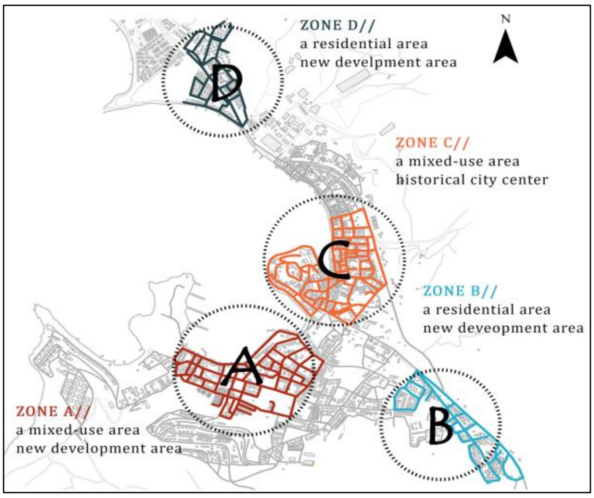

Figure 1. Study area: the selected neighborhoods

3. Results

3.1. Morphological characteristics

In order to understand the morphological characteristics in these environments, the street network characteristics and the dominant urban landuse in each selected site was investigated via spatial statistical analyses and via indices of Graph Theory and Space Syntax.

Both the Graph Theory and Space Syntax calculations are based on geographical relations between edges (streets) and nodes (intersections). Given that, street data is obtained from the archival data of Foca Municipality and updated via Google Earth. The streets were digitized and converted into nodes (intersections) and edges (street segments) (Figure 2). Then for each zone ; the total number of edges and nodes and the the total length of edges were calculated via ArcMap10.2.

Figure 2. The nodes and edges graph

Five indices of Graph Theory was calculated for the selected 4 zones ; (1) Beta index, (2) Eta index, (3) Edge density, (4) Node density, and (5) Edge sinuosity. “Beta index”, is the average number of edge per nodes. Higher scores indicate more complicated networks, which offer high number of alternative routes. It is assumed that, higher beta index scores encourages people to walk more. “Eta index”, is the average edge length. Higher scores indicate the presence of longer street segments in the area which is not appropriate for pedestrians but preferred by motor vehicle drivers or passengers. “Egde density”, is the ratio of the total length of edges to the total area. Higher scores indicate higher ratio of street area in the whole landuse. Higher street densities are observed in dense urban areas where people tend to walk. “Node density”, is the ratio of the total number of nodes to the total area. Higher scores indicate more complicated networks with shorter street segments, which offer high number of alternative routes. Given that, higher node density scores represents areas which are desired by pedestrians. “Edge sinuosity” measures straightness. It is the ratio of the shortest distance between the two ends of an edge to its actual length. Higher values indicate lower distances between destinations. As people tend to use the shortest distances while walking, higher sinousity values correlate with higher walkability.

Table 1 shows that; node density, beta index and sinousity did not vary much between zones. However B and D has higher edge density (more street area among the landuse) and zone B and C has higher eta index (longer street segments in the area). Considering the fact that, higher edge densities and lower eta indexes are desired by pedestrians zone D seems to be more preferrable by pedestrians based on Graph Theory Indices.

Three indices of space syntax was measured via ArcMap 10.2 and its extension Spatial Design Network Analysis (which was developed by Cardiff School of Planning & Geography and the Sustainable Places Research Institute); (1) Betweenness score, (2) Link connectivity score and (3) Centrality score (mean euc dist 400). The measures were based on Euclidean distances. “Betweenness score” measures the number of times the link lies on the shortest paths between other pairs of street segments. In other words, it measures the total number of shortest paths (between various potential destinations) that pass the street segment. Higher scores indicate that the street segment is a busy street which is preferred by pedestrians. “Link connectivity” measures the number of other street segment ends to which that street segment is connected. Higher scores indicate high number of alternative routes linked to a street segment, which is desired by pedestrians. “Centrality” score measures the difficulty (on average) of navigation to all possible destinations from each street segment. Higher scores indicate the street segment is located in the center of the street network and which in return refers to higher walkability in the area. After calculating the "Betweenness", "Link connectivity" and "Centrality" for each street segment the minimum, maximum and average values for each selected neighborhoods was calculated (Figure 3, Figure 4, Figure 5). Table 2 shows that zone C and zone A has the highest and zone B and D has the lowest averages for "Betweenness", "Link connectivity" and "Centrality" scores. As higher scores indicates higher walkability, zone C and A seems to be more preferrable area by pedestrians based on space syntax indices.

Next using spatial statistics; the density of each landuse in each zone was calculated using the street segment as unit of measurement. In order to that, first the location of residential areas, commercial activities, other services (such as schools, hospitals etc.) was obtained from the archival data of Foca Municipality. Next, that data was updated and corrected via Google Earth and on site visits and the function of each building and parcel along a street segment was specified. Then, the total building area along a street segment and the proportion of residential, commercial and service building (health, education, cultural activities etc.) areas along a Street segment was calculated for 15 meter buffer zone of each street segment. Finally, the average ratio of each landuse in each zone was calculated. Pedestrians tend to walk in areas with high destination variability. Given that, higher ratio of commercial and service buildings along the street scape encourages people to walk compared to higher ratios of residential buildings. As expected, residentail building density was lowest for Zone C, and commercial and service building density was highest for zone C. In brief, considering the landuse, zone C is more preferable than the other zones for pedestrians.

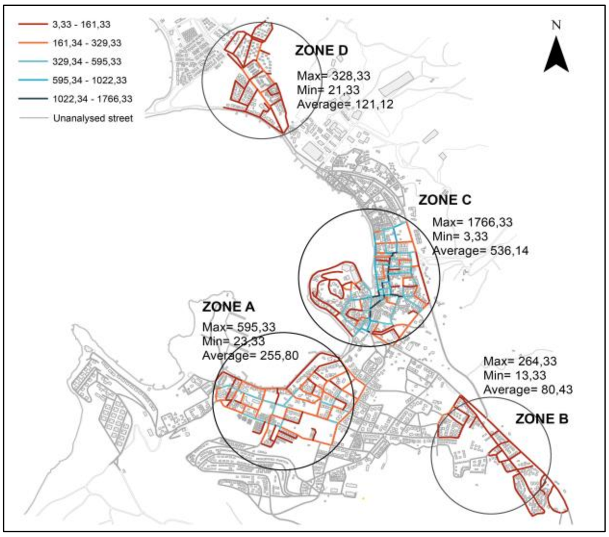

Figure 3. Betweenness score (Euc R 400)

Figure 4. Link connectivity score

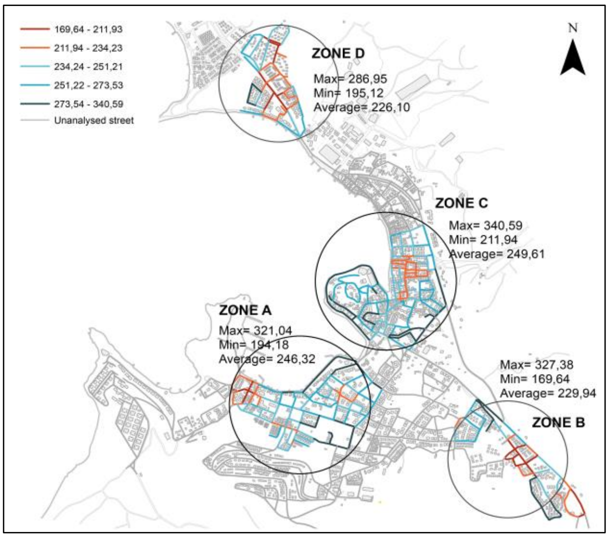

Figure 5. Centrality score (Mean Euc R 400)

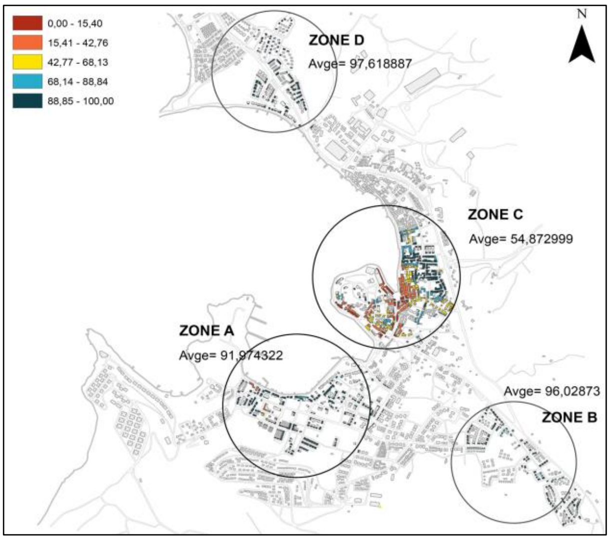

Figure 6. Residential building density

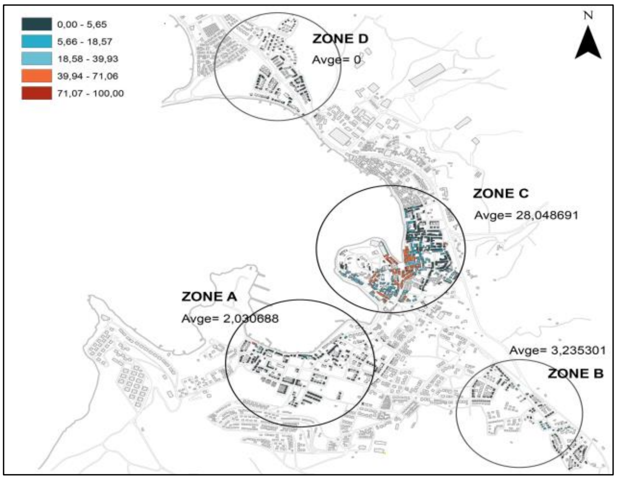

Figure 7. Commercial building density

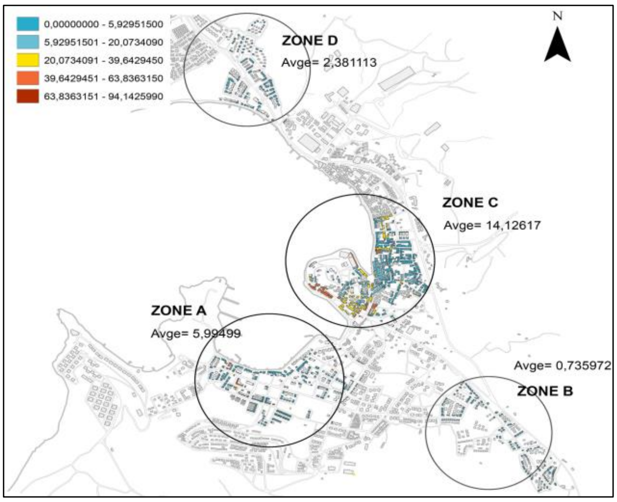

Figure 8. Service building density

3.2. Physical environmental qualities:

In order to understand the physical environmental qualities in 4 zones, four indices were calculated using spatial statistics ; (1) Proportion of buildings that pedestrians escape (empty buildings, abandoned buildings, commercials such as auto repair or hardware store). (2) Proportion of parcels that pedestrians escape (empty parcels, parcel that include abandoned buildings, parcels that include commercials such as auto repair or hardware store). (3) Proportion of pop of cafes on the street that attract pedestrians (4) proportion of green areas that attract pedestrians. In order to that, first the location of green areas and empty parcels were obtained from the archival data of Foca Municipality. Next, that data was devloped and corrected via on site visits and the empty and abondened building and parcels along a street segment was specified. Similarly the location of nice green areas (green space, sports court, playground), pop up cafes and the commercial areas that encourage (e.g. textile stores and resturants) and discourage (e.g. hardware stores) pedestrians were identified. Then, the total area along a street segment and the proportion of recreational areas, pop up cafes as well as buildings and parcels that pedestrians escape along a street segment were calculated for 15 meter buffer zone of each street segment. Pedestrians are willing to visit areas that involve pop-up cafes and green areas and escape from areas that involve empty buildings, abandoned buildings, commercial areas that are not appropriate for pedestrians (such as auto repair and hardware store) and empty parcels.

Table 4 shows that; Zone C involves the building types that pedestrians escape more than other zones, and Zone A, B and C involves the parcel types that pedestrians escape more than Zone D. Pop-up cafes that attract pedestrians are highest in zone C and recreational areas that attract pedestrians are highest in zone B. Given that, parcels and buildings that push pedestrians out of the area are concentrated in zone C. On the contrary the pop-up cafes that invite pedestrians into the area are also concentrated in zone C. In other words both the negative and the positive physical environmental qualities are concentrated in zone C which is the center of a small town.

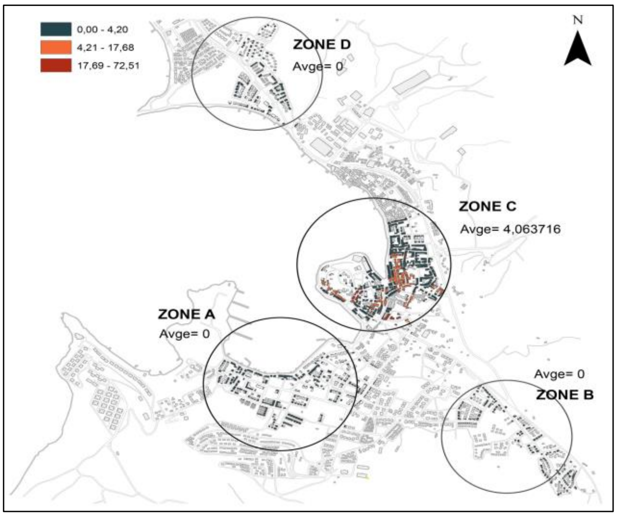

Figure 9. Proportion of buildings that pedestrians escape

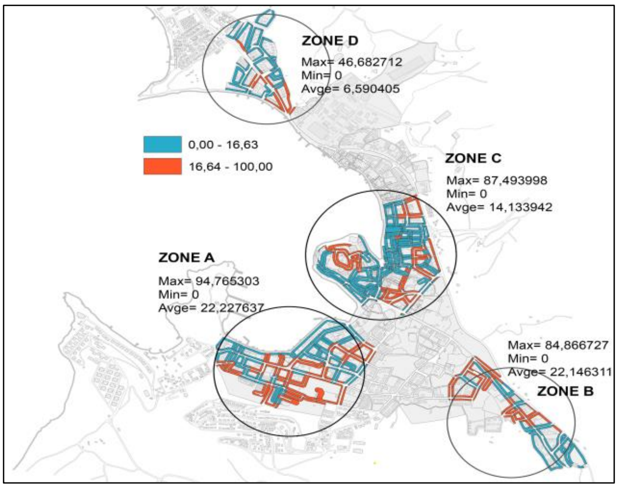

Figure 10. Proportion of parcels that pedestrians escape

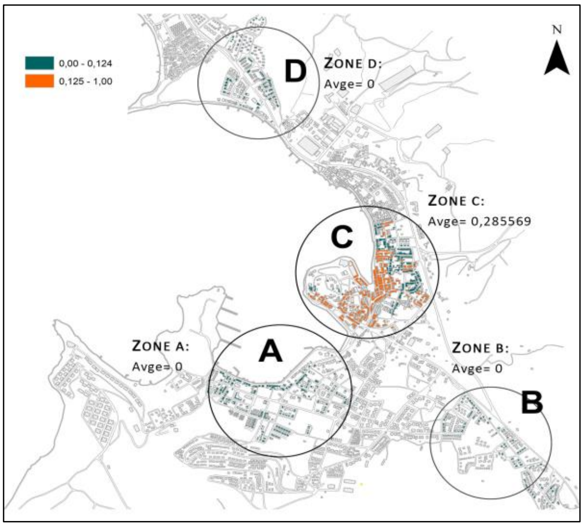

Figure 11. Proportion of pop-up cafes

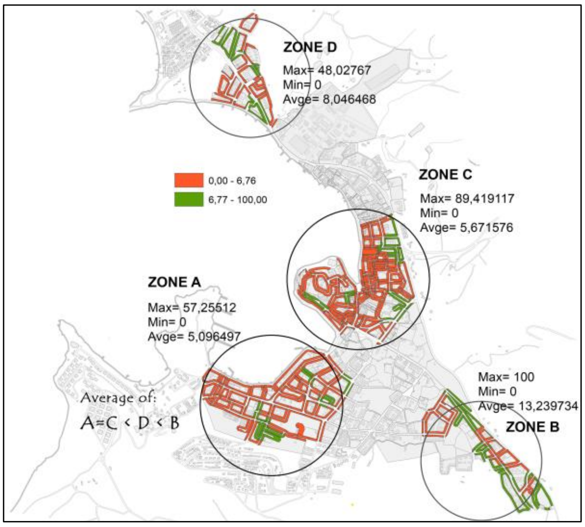

Figure 12. Proportion of recreational areas

Table 1. Results for Graph theory indices

Zone	Edge Density	Node Density	Eta Index	Beta Index	Sinuosity		
	Average	Average	Average	Average	Minimum	Maximum	Average
Zone A	0,0282	0,0003	75,08	1,40	0,719	1,000	0,979
Zone B	0,0341	0,0003	102,75	1,27	0,314	1,000	0,950
Zone C	0,0151	0,0003	102,75	1,46	0,331	1,000	0,971
Zone D	0,0325	0,0003	86,80	1,34	0,356	1,000	0,962

Table 2. Results for Space syntax indices

Zone	Betweenness			Link Connectivity			Centrality		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
ZoneA	23,333	595,333	255,809	2,000	6,000	4,524	194,177	321,040	246,319
ZoneB	13,333	264,333	80,428	2,000	6,000	4,095	169,642	327,380	229,936
ZoneC	3,333	1766,330	536,141	2,000	6,000	4,253	211,935	340,588	249,609
ZoneD	21,333	328,333	121,120	2,000	5,000	4,021	195,123	286,953	226,095

Table 3. Spatial statistical analyses for landuse density

Zone	Residential Building Density			Commercial Building Density			Service Building Density		
	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
ZoneA	7,596	100	91,974	0,000	87,930	2,031	0,000	92,404	5,995
ZoneB	54,513	100	96,029	0,000	45,487	3,235	0,000	15,842	0,736
ZoneC	0,000	100	54,873	0,000	100,000	28,049	0,000	94,143	14,126
ZoneD	10,026	100	97,619	0,000	0,000	0,000	0,000	89,974	2,381

Table 4. Spatial Statistical Analyses for physical environmental quality

Zone	Proportion of Buildings that Pedestrians Escape			Proportion of Parcels that Pedestrians Escape			Proportion of Pop-up Cafes that Attract Pedestrians			Recreational Parcel Density		
	Min	Max	Avge	Min	Max	Avge	Min	Max	Avge	Min	Max	Avge
ZoneA	0,000	0,000	0,000	0,000	94,765	22,228	0,000	0,000	0,000	0,000	57,255	5,096
ZoneB	0,000	0,000	0,000	0,000	84,867	22,146	0,000	0,000	0,000	0,000	100,00	13,240
ZoneC	0,000	72,51	4,064	0,000	87,494	14,134	0,000	1,000	0,286	0,000	89,419	5,672
ZoneD	0,000	0,000	0,000	0,000	46,683	6,590	0,000	0,000	0,000	0,000	48,028	8,046

Table 5. General results

			Zone A	Zone B	Zone C	Zone D
Morphological Characteristics	Graph Theory Indices	Edge Density		■		■
		Node Density				
		Eta Index	■			■
		Beta Index				
	Space Syntax Indices	Betweenness	■		■	
		Link Connectivity	■		■	
		Centrality	■		■	
	Landuse Parameters	Residential Building Density			■	
		Commercial Building Density			■	
		Service Building Density			■	
Physical Environmental Quality Parameters		Recerational Parcel Density		■		
		Proportion of Buildings that Pedestrians Escape	■	■		■
		Proportion of Parcels that Pedestrians Escape				■
		Proportion of Pop-up Cafes that Attract Pedestrians			■	

"Black" cells indicate walking is supported and "white" cells indicate walking is not supported based on the measurement.

4. Discussion and Conclusion

This study aims to compare the density of physical environmental qualities in four neighborhoods with different morphological characteristics. Table 5 shows how each zone is evaluated considering the extent to which the morphological characteristics and physical design qualities supports walking in the area. For example, in zone A walking is supported based on eta index, space syntax indices and one parameter for physical environmental quality (low proportion of buildings that pedestrians tend to escape from). However, the pattern in Table 5 is vague. In other words, considering the morphological characteristics Zone C seems to be superior than other zones in supporting walking in the neighborhood. Considering the fact that, zone C is mainly a commercial zone and other zones are dominated with residential buildings this is an expected result. Space syntax indices support that finding and show that street network character in zone C and A is different than other zones (this is an expected result as zone C and A are adjacent to each other). However, graph theory indices fail to show this difference. Why one measure of street network (space syntax indices) shows parallel results with landuse differentiation but other measure of street network (graph theory indices) fail to capture this differentiation deserves to be investigated in further studies with larger data sets from different sizes of cities, towns and villages. Investigating the reasons behind this difference is beyond the scope of this study.

Considering the relation between morphological characteristics and physical design qualities, table 5 suggest that; zone C inherits different morphological characteristics (commercial activities concentrated and street network shows centrality for this area). In addition, both the negative and the positive physical environmental qualities can be observed in zone C. In parallel, Zone B and Zone D; which can be defined as residential areas, differ in both street network characteristics and in presence of positive and negative environmental qualities. For example the residential area which is at the periphery (zone B) has more recreational attractions for pedestrians and the residential area at the periphery and by the sea shore (Zone D) has more empty and abondened buildings and parcels that pedestrians escape from. In conclusion, the results provide partial support for the main hypothesis (physical environmental quality differs by environmental morphological characteristics). More research are on call to expand the findings for different size of cities.

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