THE URBAN PATTERNS IN “INFORMAL” AND “FORMAL” NEIGHBORHOODS: A GRAPH THEORY-BASED STUDY

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Abstract
The urban “informal” neighborhoods in developing countries are the spatial outcomes of the informal economic relations and practices in cities. The emerge of these neighborhoods in Turkey goes back to the 1965’s in parallel to the rapid growth of private industry, followed by an immense amount of migration to big cities. The urban patterns of these “informal” neighborhoods can still be traced. In this study, the graph theory is used to compare the spatial structure of “formal” and “informal” neighborhoods of Izmir. Two neighborhoods to represent “formal” and “informal” urban patterns are selected: (1) Bostanli and (2) Ballikuyu . Six different graph theory-based centrality indices are calculated for each neighborhood: (1) edge density, (2) edge sinuosity, (3) eta index, (4) node density, (5) order of a node, and (6) beta index. The results showed that the urban street patterns pertaining to “formal” and “informal” neighborhoods of Izmir, measured through graph theory-based centrality indices, are remarkably different, and the results are statistically significant. However, the urban street network produced through a legal process is not necessarily superior to the legal one, when the graph theory-based indices are considered. Further research may consider a broader range of time and space to generalize these results.

Introduction
The Turkish economy and society have encountered a variety of challenges and undergone great changes since 1923, when the Republic was established. The industrial era in Turkey was first initiated through state-owned enterprises in 1934. The late 1940’s were characterized by rapid industrialization, followed by social change. Istanbul and its vicinity was the predominant center for private industrial activity. The Aegean Region was the next big center for industrial activity, lead by Izmir, an important export city (Alexander, 1960).
Izmir is currently the third largest city in Turkey. During the ancient times Izmir, or the Greek “Smyrna”, was one of the largest seaports on the Aegean coast of Anatolia. It was one of the three great cities of Asia Minor during Roman Times with Pergamum and Ephesus. At the end of the fourth century, Roman Empire has split into Eastern Roman (Greek Byzantine) Empire and Western Roman (Latin Roman) Empire. Izmir then became the capital of a Byzantine providence. Ottoman Turks took Izmir in 1425 (Freely, 2004). Following the devastating earthquake in 1686, the city experienced a remarkable growth, and become one of the major ports of the eastern Mediterranean (Wagstaff, 1985).
Izmir has become a city that reflects the characteristics of the modern Turkish Republic in the twentieth century (Goffman, 1999). The accelerated growth of private industry in the 1960’s has triggered an immense amount of migration to big cities, and Izmir was not an exception. The urban “informal” neighborhoods in Izmir, as in the case of other cities in the developing countries, were the spatial outcomes of the informal economic relations and activities in cities. The cities have grown in two different ways, planned and unplanned. This study aims to show that the spatial patterns that emerge as a results of the “informal” activities differs from the ones developed through a planning process. The graph theory is used to compare the spatial structures of “formal” and “informal” neighborhoods of Izmir.

Method
The graph theory is a branch of mathematics that deals with graphs. In recent years, the graph theory has been successfully adapted to various fields, and applications have been developed. Nodes (or vertices, or points) and edges (or links, or lines) are the basic elements of a graph, and the graph is a representation of a set of binary relationships (Bin and Zhongyi, 2010). In Figure 1, a graph with five nodes and eight edges are presented. As seen in Figure 1, node “a” has relations with the nodes “b”, “d”, and “c”. However, there is no relation between the nodes “b” and “c”. As it is clear from the graph, not all intersections of edges constitute a node.

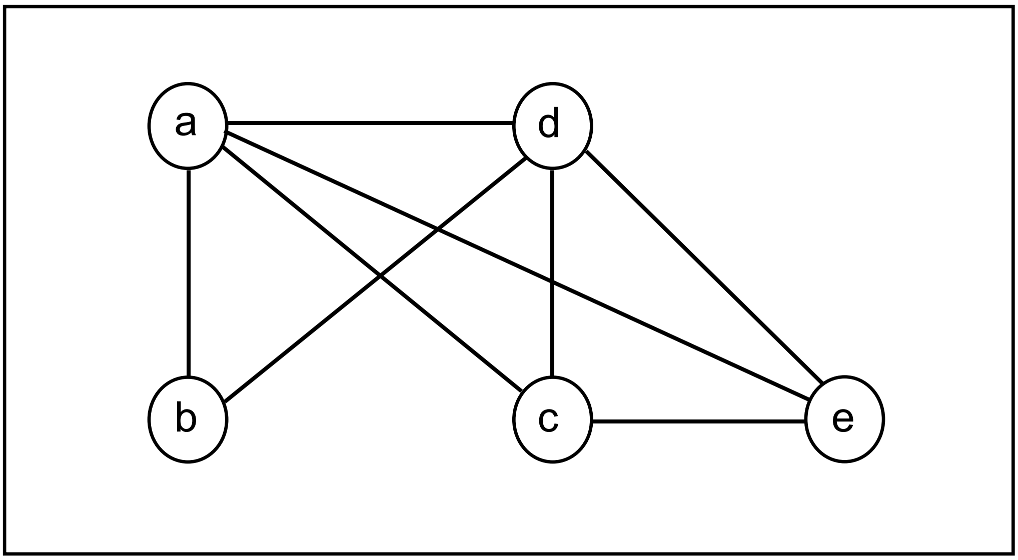

Figure 1. A graph with five nodes and eight edges

A variety of indices have been developed based on the graph theory to quantify the spatial characteristics of urban street networks. However, a majority of the analyses that utilize the indices developed within the graph theory framework are limited to the calculation of these indices and evaluating them quantitatively. Borusso (2003), for example, calculated route density indices for the Trieste Municipality area in Italy. Crucitti et al. (2006) examined the urban street patterns in 18 world cities using four node centrality indices: (1) closeness centrality, (2) betweenness, (3) straightness, and (4) information, are evaluated to. Buhl et al. (2006) analyzed a sample of street patterns from 41 non-planned settlements in Africa, Central America, Europe, and India. Cubukcu (2015) compared the spatial structure of street networks in the quarters (neighborhoods) of Izmir, Turkey, in the 19th century using graph theory-based indices. Cubukcu (2015) concluded that the urban street patterns vary with the cultural landscape, and religion may have a determining role in forming the spatial urban patterns.

In this study, six different indices are used to analyze and compare the urban spatial patterns in “formal” and “informal” neighborhoods of Izmir. These indices are: (1) edge density, (2) edge sinuosity, (3) eta index, (4) node density, (5) order of a node, and (6) beta index. Edge density is the ratio of the total length of edges to the total area. Edge sinuosity is a measure of straightness. It is the ratio of the shortest distance between the two ends of an edge to its length. Sinuosity is equal to 1 when the edge is a straight line. Node density is the ratio of the total number of nodes to the total area (Hammond and McCullagh, 1978). Order of a node denotes the number of edges intersecting at this node. Eta index is the average edge length, derived by dividing the total edge length to the number of edges. Finally, beta index, is the average number of edges per node, derived by dividing the total number of edges to the total number of nodes (Kansky and Danscoine, 1989).

Data and Analysis

Two 1-kilometer radius areas in Izmir are chosen to represent “formal” and “informal” neighborhoods. The first area is chosen from Bostanli, a high-income and high-educated neighborhood developed through a legal planning process located in northern Izmir, to represent a “formal” neighborhood. The second area is chosen form Ballikuyu, a low-income and low-educated neighborhood developed through an informal development process located in central Izmir, to represent an “informal” neighborhood. The locations of the selected areas and their aerial photos are presented in Figure 2 and Figure 3.

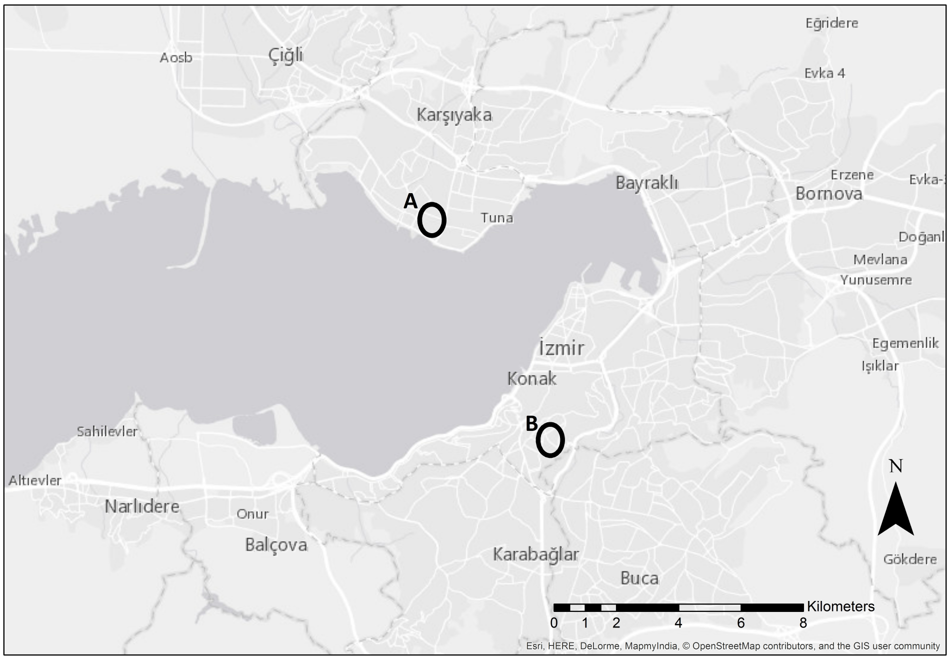

Figure 2. The locations of the selected neighborhoods (A: Bostanli, B: Ballikuyu)

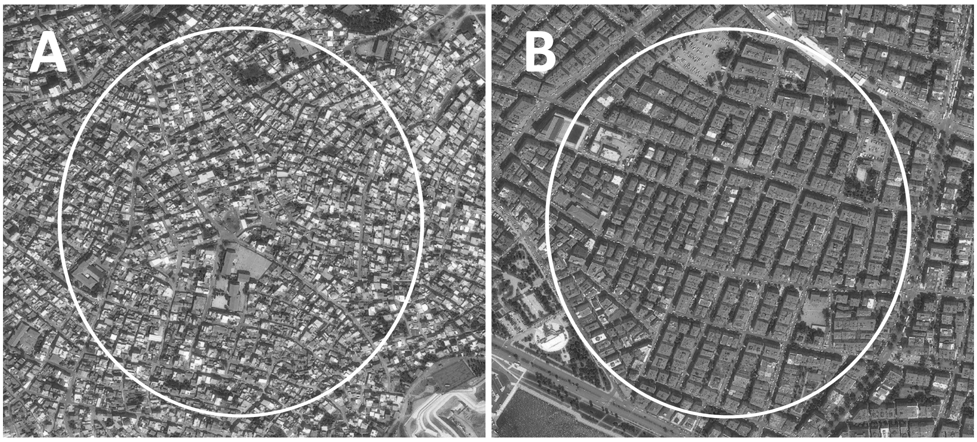

Figure 3. The aerial photos of the selected neighborhoods (A: Bostanli, B: Ballikuyu)

The street maps are derived from the OpenStreetMap, an openly licensed map of the world created and updated by volunteers. These maps are then digitized and converted into nodes and edges in a GIS environment. The edges and nodes for the two selected area are shown in Figure 4. In Table 1, the total number of edges, nodes, and the total length of edges for the two neighborhoods are presented. It is clear that the "informal" neighborhood has more edges and nodes, and the total length of edges is significantly higher in the "informal" neighborhood (Table 1).

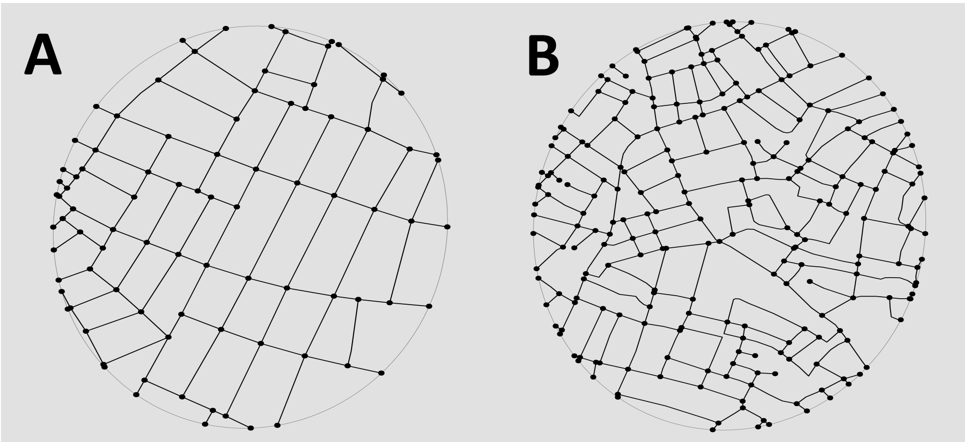

Figure 4. The nodes and edges for the selected neighborhoods (A: Bostanli, B: Ballikuyu)

Neighborhood	Total Area (m^2)	Number of Nodes	Number of Edges	Total Length of Edges
Formal (Bostanli)	37,858	89	120	8,575
Informal (Ballikuyu)	37,858	241	312	13,465

Table 1. Descriptive statistics for the nodes and edges at the neighborhood level

Using the nodes and edges presented in Figure 4, the six graph theory-based indices are calculated at the at the neighborhood level. The mean values for the six indices are shown in Table 2. As seen in Table 2, the index values are significantly different for the two neighborhoods which represent the "formal" and "informal" production of the urban space. Both edge density and node density are higher in the "informal" neighborhood. Sinuosity is slightly higher in the "formal" neighborhood, pointing to straighter streets in the "formal" neighborhood. The average edge length, measured as the eta index, is higher in the "formal" neighborhood indicating longer street segments in the "formal" neighborhood accompanied by less number of edges per node, measured by the beta index. These results indicate that the urban street network produced through a legal process is not necessarily superior to the one developed by a legal process.

Neighborhood	Edge Density	Edge Sinuosity	Eta Index	Node Density	Order of Nodes	Beta Index
Formal (Bostanli)	0.2265	0.9999	71.4545	0.0024	2.696629	1.3483
Informal (Ballikuyu)	0.3557	0.9866	43.1581	0.0064	2.589212	1.2946

Table 2. Descriptive statistics for the nodes and edges at the neighborhood level

Index	Descriptive	Formal (Bostanli)	Informal (Ballikuyu)
Eta Index (Edge Length)	n	120	312
	Minimum	4.7064	1.2674
	Maximum	200.4166	171.6240
	Mean	71.4545	43.1581
	Standard Deviation	40.9859	27.9635
Edge Sinuosity	n	120	312
	Minimum	0.9931	0.6270
	Maximum	1.0000	1.0000
	Mean	0.9999	0.9866
	Standard Deviation	0.0006	0.0512
Order of a Node	n	89	241
	Minimum	1	1
	Maximum	4	4
	Mean	2.6966	2.5892
	Standard Deviation	1.1937	1.0069

Table 3. Descriptive statistics for the three indices at the node or edge level

Further, three of these indices: (1) edge sinuosity, (2) edge length, and (3) order of a node are calculated at the edge or node level. The pertaining descriptive statistics are presented in Table 3. The mean values for these three indices for the two neighborhoods ("formal" and "informal") are compared using independent-samples t-test. The results show that the two indices for the two neighborhoods do not belong to the same population. That is to say, the null hypotheses that these neighborhoods have equal means are rejected for the two indices, edge sinuosity and edge length. The fidings are statistically significant at the 0.01 level. The t-statistics are -6.939 and -4.575, for the eta index and edge sinuosity respectively, when the variances are assumed to be unequal. However, the null hypothesis that the "formal" and "informal" neighborhoods have equal means in terms the order of nodes cannot be rejected at the 0.05 level, indicating that they have similar means in terms of the "order of a node" index.

Conclusion

In this study, the graph theory is used to compare the spatial structures of "formal" and "informal" neighborhoods of Izmir. Six different spatial indices are calculated: (1) edge density, (2) edge sinuosity, (3) eta index, (4) node density, (5) order of a node, and (6) beta index. All of these six indices are first calculated at the global level. Further, three of these indices including edge sinuosity, edge length, and order of a node are calculated at the edge or node level.

The results showed that the urban patterns produced through a legal planning process and an informal development process differ significantly. Thus urban patterns of the so-called "informal" neighborhoods can still be traced. Moreover, the urban street network produced through a legal process is not necessarily superior to the legal one, when the graph theory-based indices are considered. Further research may consider a broader range of time and space to generalize these results.

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