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Exploring the Microstructure of the Urban Street Network: Layout Pattern Versus Centrality*

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ABSTRACT

Studying the urban street network, as one of the constituent elements of urban form and the commonality of the two systems of movement and activity, plays a significant role in understanding the dynamic events in the city and solving the problems resulted from the conflicting function of the two abovementioned systems. One of the most effective structural characteristics of the street network is street network centrality which has a substantial effect on the distribution of activities and accordingly on the formation of motorized and pedestrian traffic flow throughout the city. On the other hand, one of the most important elements influencing on the network centrality is street layout. The current article aims at explaining the relationship between street layout pattern and centrality at the local scale or the microstructure of the street network. The city of Qom is an example of an old city in Iran that has an ancient urban fabric in the central core of the city and a diverse range of street layout in the middle and peripheral parts - with distinct structural features. Thus, this city is an appropriate context as the study area to explore the microstructure of the urban street network. The research process is as follows; After identifying the relatively homogeneous central zones in terms of morphology in the study area by modelling street network centrality using Multiple Centrality Assessment (MCA) method in terms of centrality index of local closeness, and applying some considered criteria, the street layout pattern of the selected zones is analyzed using several indicators of street centerline as well as blocks. Finally, the relationship between indicators of street layout pattern and the average local closeness network centrality index is explained by building a correlation matrix using Pearson's correlation coefficient. Findings show that just 3 out of 10 selected indicators of the street layout pattern - all of which are indicators of the network centerline - have a significant correlation with average local closeness centrality index. Therefore, average local closeness centrality index has no significant correlation with block indicators. The correlation matrix shows that the higher the network lenghth as well as the proportion of three-way intersections throughout the local fabric area, the higher the average local closeness centrality index of the street network; consequently, the more centralized fabric will be at the scale of pedestrian accessibility.

Keywords: Street Layout Pattern, Street Network Centrality, Multiple Centrality Assessment (MCA), Pearson's Correlation Coefficient.

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1. INTRODUCTION

The street network is the constituent element of the urban form and structure and connects the public spaces of the city since the public space of the city as a whole consists of a connective chain of the streets. The urban street network pattern requires considerable attention due to its structural role in recognizing the existent fabric of the cities as well as designing the new parts (Marshall, 2005). The urban layout is the arrangement and configuration of the streets, blocks, and buildings and is often at the street scale, such as the grid or tree-like street layouts. The street layout is the urban street network shape in terms of pattern, structure, and quantitative features. The layout of today's cities is the result of historical development, planning, and construction regulations. The configuration of the street network, in terms of its urban block size, their overall location within the city, pedestrian and vehicular connectivity can affect the functioning of a city by, for example, influencing the location and intensity of activities (As cited in Dempsey et al., 2010, p. 25; Penn, Hillier, Banister, & Xu, 1998; Porta et al., 2009). The street layout is one of the most significant factors affecting the centrality of a place. The central places of a city can be recognized considering the street layout through studying "street network centrality". A central place because of its features has a special location for living and activity: suitable accessibility from immediate surroundings and more distant places. Suitable accessibility leads to visibility and popularity, which is considerable for the location of commercial activities. The location of the commercial and service units is a significant matter in their efficiency and survival. Therefore, these units are located in a place that has a central position. Out of the features of the central places, are the higher real state value and higher density of land use and activity (As cited in Newman & Kenworthy, 1999; Porta et al., 2010, pp. 107-108; Portal et al., 2009, p. 450). Hillier (1999) believes that the term "center" has two distinct aspects of meaning: functional and spatial, functionally, it means concentration and distinctive mix of the land uses and activities in a certain area, and spatially, it refers to a certain position of that area in the settlement as a whole (Hillier, 1999, p. 1).

Due to the increasing use of motorized vehicles and the high volume of intra-city trips, one of the problems of today's cities is the functional interference of the two systems of movement and activity. A closer look at urban spaces, especially city streets as the commonality of the two abovementioned systems and the context of this interference, shows how the improper structure of the street network of a city can disrupt the performance of both systems. Therefore, it is required that by studying and investigating the origins and influential factors, purposefully improve the relationship between two systems of movement and activity. The recognition and analysis of the relationship between the street layout and centrality, as the structural features of the city's street network, lead to a substantial contribute to explaining the function of the activity and movement systems in the city. Qom city is one of the old cities of Iran that has a unique urban fabric in the central core of the city, like other old cities, and a variety of the street layout in the middle and peripheral parts. Therefore, this city provides a suitable context for exploring the microstructure of the street network of the city. With the goal of explaining the relationship between the street network centrality and layout patterns at the local scale, the current research aims at answering the question that how to explain the relationship between the street network centrality index and layout patterns at the local scale of the central zones of Qom city. Thus, the initial yet influential step can be taken to identify the origins of the problems resulted from the interference of the movement and activity systems in this city.

2. RESEARCH METHOD AND TOOL

The research method and tool are the basis of each research to answer the questions and achieve the goals. In the following, each of the methods and tools utilized for the analysis of the data in the current research is presented. Then, the study area, i.e., Qom city, is introduced.

2.1. Method of Measuring the Street Layout Patterns and Network Centrality

From the urban planning and design points of view, which the both have spatial persepectives, the centrality can be explored from two aspects: land-use/density and street network. In the current paper, the centrality is assessed from the street network point of view which the recognition and measurement of the urban centrality are done by considering the structure and shape of the urban street network. According to the literature, there are two main approaches in studying the street layout pattern as a graph[1] (Fig. 1), and its centrality: topological and geometric (Hillier, 1996, 1999; Hillier & Hanson, 1984; Hillier et al., 1993; Marshall, 2005; Porta et al., 2005, 2006; Porta et al., 2010; Rashid, 2016). The topological approach analyzes the configuration of the network while the geometric (metric) approach evaluates the composition of the network (Fig. 2). The configuration is presented as an abstract diagram. The configuration is one of the concepts related to the network structure that deals with the non-metric information, such as the order (relative position) of links (edges) and nodes, connection, continuity, alignment and adjacency; but, none of the information of distances, angles and absolute areas (Fig. 2-A). On the other hand, the composition is the geometric formation of the layout as it shows in a scaled plan, the position, length, area and alignment angle of the objects (Fig. 2-B) (Marhsall, 2005, pp. 86-87). It is obvious that a special analysis method and tool must be utilized to analyze the network by each of the mentioned approaches.

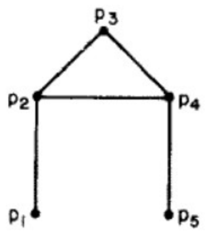


Fig. 1. A Graph Constituted of Five Nodes and Five Edges
(Freeman, 1979, p. 218)

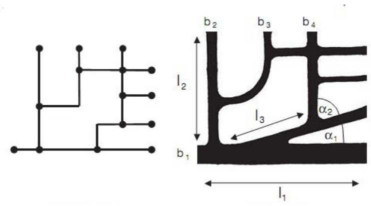


Fig. 2. (A) Network Configuration (B) and Composition
(Marshall, 2005, p. 86)

Porta et al. (2005) believe that all the approaches of the network analysis are based on the idea that some of the places or streets are more important than others because they are more "central". Regarding graph theory and the network analysis fundamentals, centrality means the most important nodes and links in terms of placement in a central position with respect to other nodes and links. The main indices of the network centrality are closeness, betweenness, straightness, and information (Freeman, 1979; Porta et al., 2005; Porta et al., 2010). Given that the current study aims at analyzing the urban zones at the local scale, the local closeness centrality index is utilized. The closeness centrality (CC) measures to what extent a node is close to all other nodes along the network geodesics. The closeness centrality index of a node is the inverse ratio of its average distance from all other nodes (Porta et al., 2010, p. 110):

$$C_i^C = \frac{N-1}{\sum_{j=1;j\neq i}^{N} d_{ij}} \quad (1)$$

N: total number of nodes
dij: geodesic length between the nodes of i and j
From another point of view, two main approaches can be taken while analyzing and modeling the urban street network graph: The primal approach and the dual approach. The primal approach is the representation of the network graph as the real or geographical shape is, in the way that it have been used in urban transportation planning to study the relationship between land uses and transportation lines. Therefore, in the primal graph of the street network, every intersection is considered as a node, and the connecting routes between the intersections are considered as an edge. On the oposite side, in the dual graph, every street, disregarding its length, is considered as a node, and every intersection is presented as an edge (Porta et al., 2005, pp. 1 & 7-9). With the widespread use of the dual approach in the study of the urban street network after the seminal work of Hiller and Hanson (1984), using a network-oriented approach to cities, neighborhoods, streets, and even buildings, the space syntax method established a considerable correlation between topological accessibility of the streets and various phenomena, such as pedestrian and vehicular traffic flow, way-finding, crime, economic life, and social livability. (Porta et al., 2006, p. 3; quoted by Hillier, 1996). Multiple centrality Assessment (MCA) method as a method for analyzing the network centrality of spatial systems, such as urban street network, using the primal approach and the concept of composition, analyzes the urban street network centrality by four centrality indices (closeness, betweenness, straightness and information). It is also distinguished from the space syntax method for the following reasons: (Porta et al., 2005, pp.1 &16).

1. MCA method is based on the primal graphical representation of the street network in comparison with the dual graphical representation applied in the space syntax. The primal approach is a more comprehensive, objective, and realistic approach for the network analysis of the centrality in the urban street network. Considering the use of the standard format in the road centerline map, and access to the huge amount of data of the cities, this approach can be implemented easier and faster and reduces subjectivism in graph construction by excluding problems related to the generalization.
2. Despite the topological framework in space syntax method, MCA method has a metric framework. While the primal approach of MCA method allows to preserve a metric and geographical concept of the distance, without abandoning the topology of the system, the dual approach applied in space syntax method leads to just a topological step-distance concept that makes indices and processes more abstract, in that it misses much of the sensorial dimensions of human ecology.
3. MCA method investigates a set of four centrality indices instead of one index, since the centrality is not a single thing but a multifaceted concept, and therefore, for a more exact and better understanding, several indices must be measured.

Recognition and measuring the urban street layout pattern is possible by quantifying and index constructing of the structural features of the network components (nodes, links, blocks, and so on), since recogonition of the general patterns as a whole is based on recognising the constituent parts (Marshall, 2005, p. 97). As the two networks might have a similar topology but different geometry, the quantification must be based on both topological and geometric (metric) features of the network (Louf & Barthelemy, 2014, pp. 1-2). Various studies have been conducted to analyze and measure the street network patterns (Buzzetti, 2017; Louf & Barthelemy, 2014; MacDougall, 2011; Marshall, 2005; Rashid, 2016; Strano et al., 2012), considering the research purpose and scale, each of the studies has used various topological and metric measures and indicators.

Measuring and assessment of layout patterns and centrality in the microstructure of the city street network should be done in the homogeneous urban zones in terms of morphology so that while analyzing and measuring layout patterns and network centrality in zones are feasible, the zones can be morphologically comparable. Determining these zones can be possible by recognizing urban barriers. The urban barriers divide the city into urban zones (superblocks). These barriers can be classified into two groups: first order and second order. The first order urban barriers are physically much more impermeable, with a high separating feature, and mainly at a regional/territorial scale. However, the second order urban barriers (urban boundaries) have less separation feature, at the scale of city/settlement, play the role of urban fabric edge. Second order urban barriers are the main traffic routes of the city (urban thoroughfares and or functional arterials). The first order urban barriers can be classified into the following groups (McDougall, 2011):

A) Natural barriers: river, steep slope lands (more than 10%), lake

B) Artificial barriers: wall (fortifications), canal, railway, highway, high-tension power-lines

C) Large mono-functional zones: rail yards; park, airport, industrial/commercial cluster.

2.2. The Correlation Analysis Method of the Street Network Centrality and Layout Pattern

The correlation matrix is used to analyze the correlation between the layout pattern indicators and the network centrality indices. The simple linear correlation coefficient (Pearson correlation coefficient) is calculated using IBM SPSS Statistics software. Pearson correlation coefficient between two random variables equals to their covariance divided by the multiplication of the standard deviation of each of them. The value of the Pearson correlation coefficient varies between -1 and 1, which indicates the proportionality of the value of the two variables to each other (Porta et al., 2009, p. 14; as cited in Porta et al., 2009, p. 461; Taylor, 1997). The positive correlation coefficient indicates the direct relationship between the variables, that is to say if one of the variables increases or decreases, the other variable increases or decreases. The negative correlation coefficient indicates the inverse relationship between the variables.

2.3. Study Area

For the verification of the accuracy and the function of each urban theory, it is mandatory to apply that in a geographical area. Therefore, the modeling of local closeness centrality of the street network of Qom city is addressed to identify the central zones at the local scale of the city in terms of the network centrality as well as analyzing and avaluating the street layout patterns in each zone and its relationship with the network centrality. The city of Qom is located in the central region of Iran, due to its position at the intersection of several inter-city roads, the extending of the roads through the city has caused the creation of a radial structure in Qom street network, which, by passing the time, has been strengthened in terms of accessibility by creating ring streets and grid networks. In figure 3, the streets colored in red are the extension of inter-city roads, and the other streets that make the macrostructure of the city street network are colored in purple. Passing the national railroad and the seasonal river "Qomrood" through the city (green and light blue colors in Figure 3, respectively) has also had a significant effect on the macrostructure of the city.

3. DATA ANALYSIS AND RESEARCH FINDINGS

The process of achieving the research findings is as follows:

1. Analyzing and modeling local closeness centrality index of the street network to identify the central zones at the local scale;
2. Determining the central zones capable for measuring and avaluating the street layout patterns;
3. Measuring and avaluating the street layout pattern of the selected central zones;
4. Analyzing the relationship between street network centrality and layout pattern of the selected central zones.

3.1. Identifying the Central Zones of the City at the Local Scale Using the MCA Method

As mentioned, the current study applies the local closeness centrality index. The output of the modeling of the mentioned index in the street network of Qom city using MCA software and ArcGIS can be seen in Figure 4. In the provided more, the degree of centrality has been marked by the dark blue (the minimum degree) to red (the maximum degree). In the provided local centrality model, the analysis radius has been considered 400 meters, which is compatible with the Neighborhood unit radius in the neighborhood unit theory of Clarence Perry (1929) (As cited in Mehaffy, Porta, & Romice, 2015, p. 202). 4000-meter distance as the appropriate accessibility distance by walking or bicycle to the services has been used in other studies such as Reneland on the accessibility of the Swedish cities (Reneland, 2000, p. 133). Therefore, the result of the conducted analysis on the local closeness centrality of the network indicates the central zones of Qom city on the local scale (neighborhood) and appropriate to the pedestrian access. Figure 4 shows the central zones (the zones with higher centrality) in the pedestrian access scale by the red color. Based on the previous research, the central zones can load higher density than the service and commercial activities.

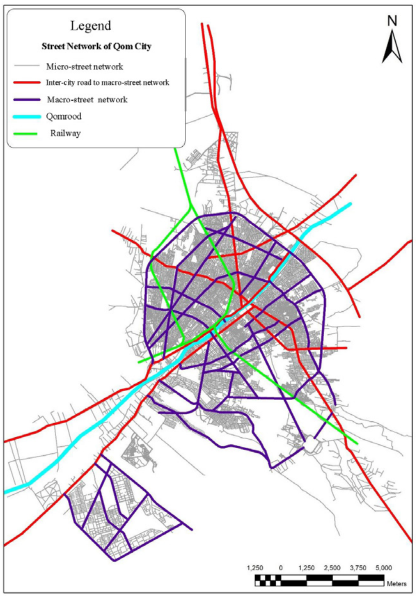


Fig. 3. The Street Network Structure of Qom City
(Qom City Municipality)

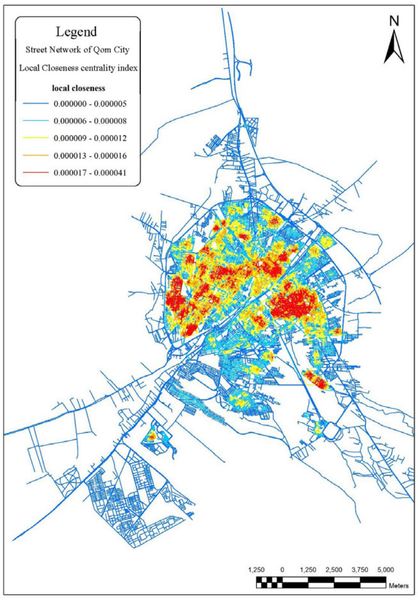


Fig. 4. The Local Closeness Centrality Model of the Street Network of Qom City

3.2. Determining the Measurable Central Zones

After determining the central zones of Qom city in terms of street network centrality, the next step is the process of the determination of the analyzable central zones and measuring the network patterns to analyze and identify the layout patterns of the street network on the local scale. Selecting the measurable central zones is a significant phase of the current study because the improper determining of the considered zones can detour the research results. The considered zones are named the local morphological zones considering the relative homogeneity of the final selected central zones morphologically (after finishing the following process). The process of determining the local morphological zones includes the following steps:
1. Identifying the urban edges (permeable and impermeable);
2. Identifying the inexplicable urban edges of the network pattern; and
3. Determining the local morphological zones.
The analysis process must be done in the zones that are homogenous morphologically. According to the research background, the boundary of the mentioned zones overlays the first row urban barriers (the impermeable edges). Also, the urban barriers of the second row overlay the urban boundaries (permeable edges) as these edges have a separating role in the urban fabric and lead to the two morphologically different fabrics in their two sides. The urban edges of Qom city include the following presented in figure 5.

3.2.1. Impermeable Urban Edges

- Natural edges: Qomrood river;
- Artificial edges: railway, highway (i.e., ring road, the centerline of Payambar Azam (PBUH), Persian Gulf), and freeway (i.e., Tehran-Qom- Kashan), the interchanges.

3.2.2. Permeable Urban Edges

- Principal arterial streets
-Minor arterial streets
As can be seen in Figure 5, the urban edges divide the city surface into the urban superblocks, which are called urban zones in the present study. It is noteworthy that all the obtained urban zones are not suitable for implementing the analysis and evaluation of the network and activity. The inexplicable urban zones of the network pattern in Qom city can be classified as follows:

3.2.3. Large Single-Functional Zones

- Transportation equipment zones (railway infrastructures, terminals, etc.)
- Workshop-industrial zones
- Urban green zones (Parks, gardens, and agricultural lands)
- Urban dirt zones (Barren and mountainous lands)
- Large single-functional blocks.

3.2.4. Incomplete Residential Zones

- Residential zones with dispersed constructions and inconsistence street network;
- Residential zones with improper geometric forms and low depth fabric
Besides the previously mentioned, the layer of the historical progress map of the physical growth of the city as well as the layer of the registered plates'

boundaries (i.e., agricultural lands and previous gardens) were also considered in order to classify the zones with inhomogeneous internal fabric due to the formation in more than one historical period or related to the one or several different registered plates and various separation into the inexplicable zones. Although, due to the lack of access to the complete data, in particular, the boundary layer of the registered plates, it was not possible to classify all the zones. After removing the inexplicable zones, which was the first screening in achieving the final selected zones, the 60 zones remained, which are called the primal selected zones marked by the yellow color in Figure 6-A. This map indicates that the stated zones placed in the central and middle fabric of the city are often the residential fabrics. Indeed, since the incomplete residential zones were eliminated, they did not cover all the central and middle fabrics of the city based on the previously mentioned. The peripheral fabric of the city also includes the large single-functional zones in addition to the incomplete residential zones that are not suitable to analyze the network pattern on the local scale.

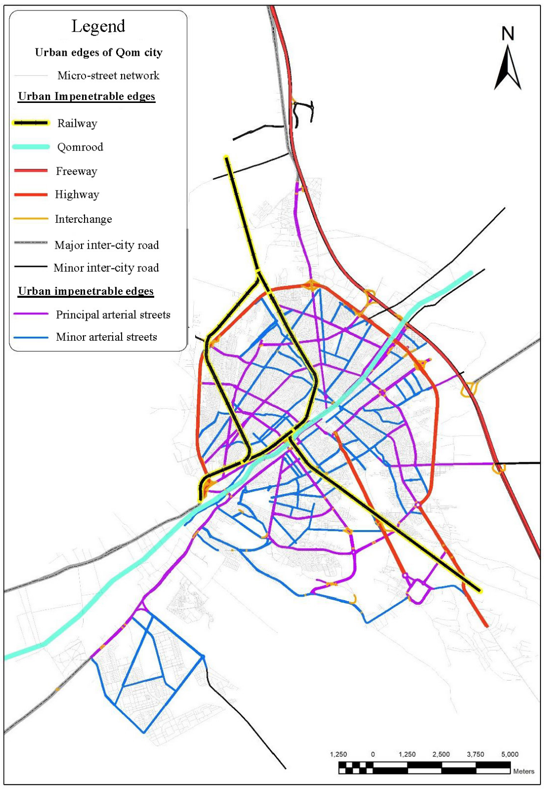


Fig. 5. The Permeable and Impermeable Edges of Qom City

The next step is to determine the final selected zones or the local morphological zones. The final zones must be capable of analyzing the network in terms of the street network. Also, they must be central and have a relatively homogenous fabric in terms of morphology. Therefore, the mentioned zones must be selected based on the criteria to meet the research purpose. Thus, given the research background and purpose, five conditions were selected for measuring 60 primal selected zones and determining the final zones. Each of the 60 stated zones that enjoy the five terms can be selected as the final selected zones:

First condition: the area of the zone must be at least 50 hectares (Circle area with a radius of 400 meters) to provide access on the local scale.

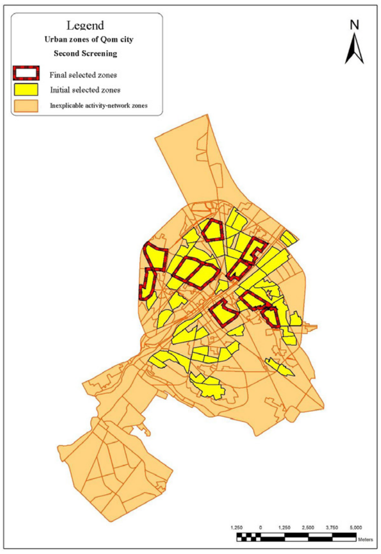
Second condition: the width of the Minimum Bounding Rectangle of the polygon boundary of the zone must provide a minimum radius of 400 meters for the perimeter circle on each part of the MBR.

Third condition: The polygon shape factor of the zone boundary should be at least 0.3 to remove zones with an unsuitable geometric shape for analysis.

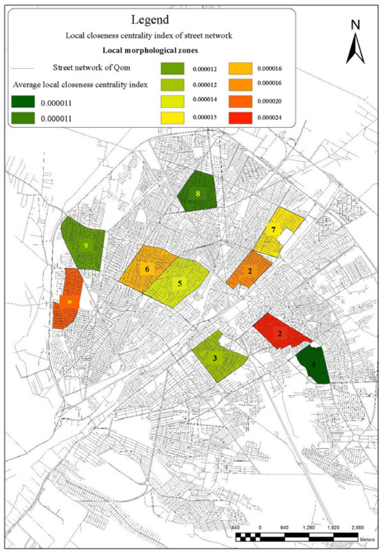
Fourth condition: The replacement index of the polygon area of the zone boundary should be at least 0.6 (by examining the frequency distribution diagram of this index in the zones) to eliminate the zones with very irregular (uncompressed) shape.

Fifth condition: the mean of the local closeness centrality index of the links within the zone must be at least equal to the mean of that index in Qom city so that the selected zones be from the central areas of the city (i.e., with high centrality). This condition is the most significant in terms of the research purpose. The process of determining the local morphological zones is conducted using ArcGIS, SPSS, and Microsoft Excel. After conducting the stated process that is the second screening of the urban zones of Qom city, ten final zones were selected as the local morphological zones (Fig. 6-A) that are named for easier recognition. The naming is conducted based on the historical period of the fabric formation of the considered zone. Map (4-B) indicates the naming of the stated zones from 1 to

10 and the mean of the local closeness centrality index of the street network of each zone. It indicates that the network centrality is not necessarily related to the age of the zone's fabric directl.



(A)



(B)

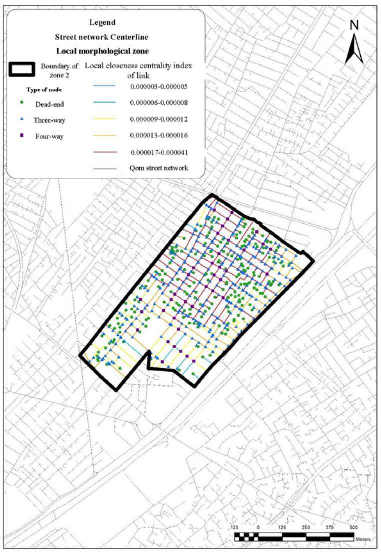
Fig. 6. (A) The Screening of the Urban Zones of Qom. (B) The Mean of the Local Closeness Centrality of the Network of the Local Morphological Zones

3.3. Evaluation of the Street Layout Pattern in the Local Morphological Zones (LMZ)

This section analyzes the characteristics of the layout pattern of the street network in the microstructure of the network on the local scale. The features of the street layout pattern are analyzed in two main groups of street network centerline and block. According to the available place-based data, the layers of the considered map were produced using the capabilities of ArcGIS. The map of the street network centerline in each zone indicates the links of the network, and their coloring is based on the value of the local closeness centrality index as well as the different types of nodes (i.e., three-way, four-way, and dead-end) (Fig. 7). The block map of each zone also indicates the location of the blocks within a zone (Fig. 8). As can be seen in Figure 7, by increasing the number of dead-end in an area, the number of three-ways also increases. As every dead-end is branched from a three-way, therefore, the number of nodes in that area increases. Since the blocks are like the islands and their boundaries are the street network, the block map is considerably influenced by the street network centerline map of each zone. Thus, the more compact and dense the centerlines of the street network in an area, the less area the blocks will have and vice versa. The more comprehensive and precise findings are obtained by calculating the indicators and criteria and using the correlation coefficient between the indicators considering the research purpose.

A comprehensive list of criteria related to the street layout pattern and the calculated indicators of the composition of the criteria was provided by studying the research background as well as the available data. It is noteworthy that to have a significant comparison between the features of the network pattern of zones with each other, the indicators must be considered alone. The number of indicators to measure the layout of the street network is 30 indicators in total (i.e., 19 indicators of the street network centerline and 11 indicators of the blocking) that were numbered for analysis (Table 1). The indicators relevant to the local closeness centrality of the links are also removed to prevent the deviation of the results while investigating the relationship between the centrality and the network pattern. Besides, considering that there are only two types of three-way and four-way intersections in the zones, the total of intersections means the total three-way and four-way intersections.

Before analyzing the indicators, two indicators with high correlation (at the significance level of 0.01) must be identified so that one of them be eliminated from the analysis process. Therefore, the excessive emphasis will not be on one feature. By using the analytical tools of SPSS software, a correlation matrix must be created between the 30 stated indicators. After analyzing and studying the indicators with high correlation, considering the research purpose and background, ten indicators (i.e., four network centerline and six block indicators) were selected for the final analysis of the network patterns, presented in Table 1 in a bold font. Table 2 indicates the descriptive statistics of the selected indicators.


Legend
Street network Centerline
Local morphological zone
Boundary of zone 2
Local closeness centrality index of link
Type of node
Dead-end
Three-way
Four-way
0.000003-0.000005
0.000006-0.000008
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Qom street network
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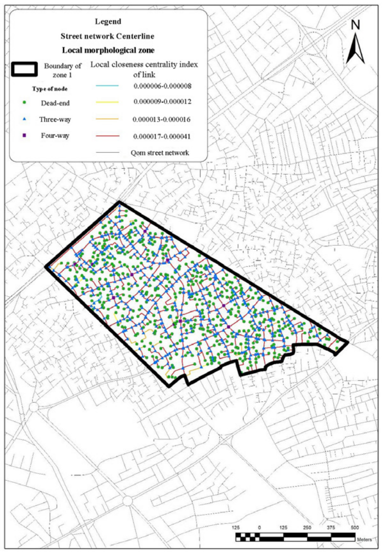
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Street network Centerline
Local morphological zone
Boundary of zone 1
Local closeness centrality index of link
Type of node
Dead-end
Three-way
Four-way
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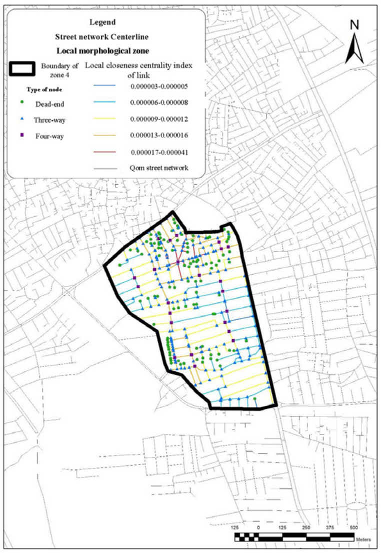
Legend
Street network Centerline
Local morphological zone
Boundary of zone 4
Local closeness centrality index of link
Type of node
Dead-end
Three-way
Four-way
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0.000006-0.000008
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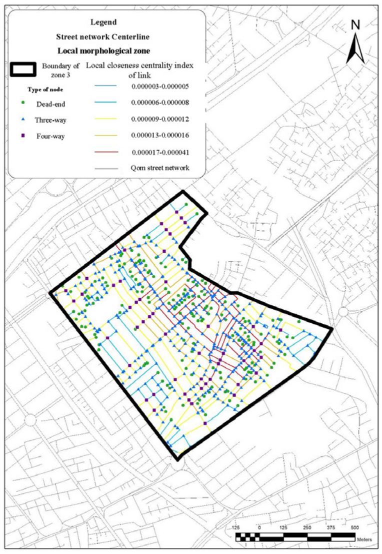
Legend
Street network Centerline
Local morphological zone
Boundary of zone 3
Local closeness centrality index of link
Type of node
Dead-end
Three-way
Four-way
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0.000006-0.000008
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Qom street network
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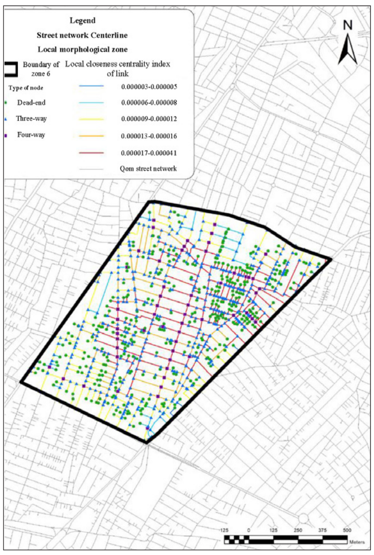
Legend
Street network Centerline
Local morphological zone
Boundary of zone 6
Local closeness centrality index of link
Type of node
Dead-end
Three-way
Four-way
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0.000006-0.000008
0.000009-0.000012
0.000013-0.000016
0.000017-0.000041
Qom street network
N
125 0 125 250 375 500
Meters

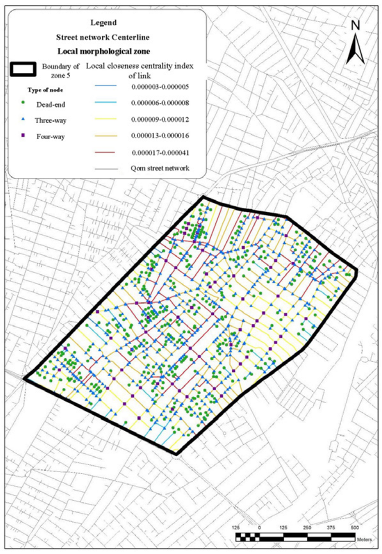
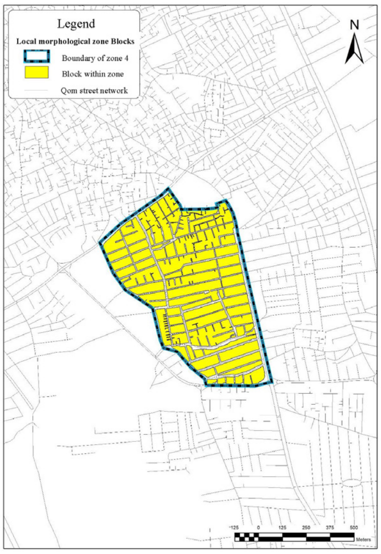
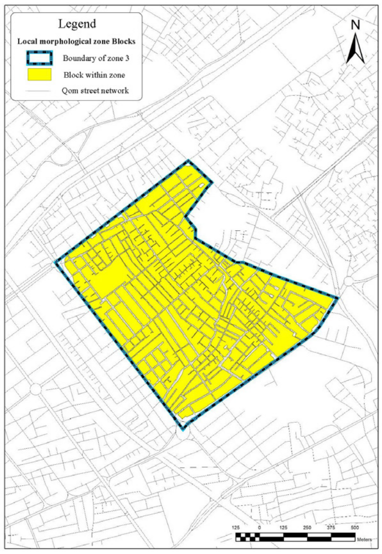
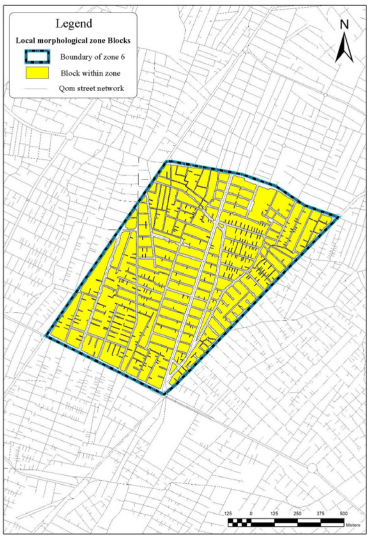
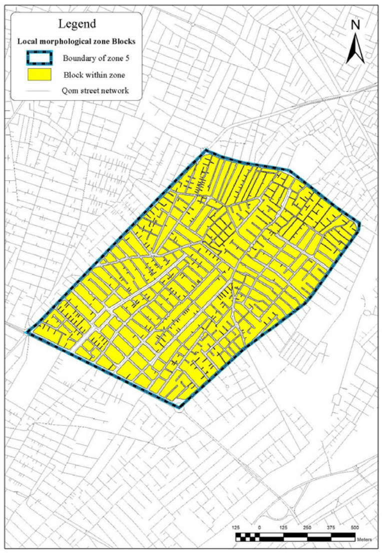

Legend
Street network Centerline
Local morphological zone
Boundary of zone 5
Local closeness centrality index of link
Type of node
Dead-end
Three-way
Four-way
0.000003-0.000005
0.000006-0.000008
0.000009-0.000012
0.000013-0.000016
0.000017-0.000041
Qom street network
N
125 0 125 250 375 500
Meters

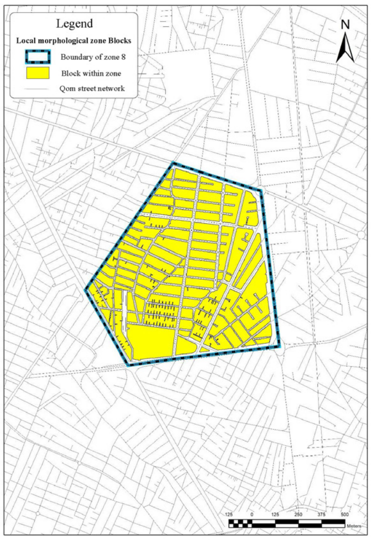
Fig. 7. The Street Network Centerline in 10 Local Morphological Zones

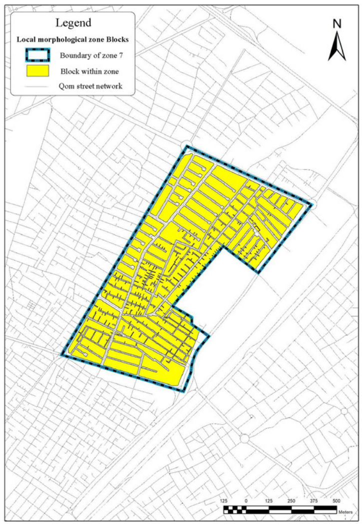

Legend
Local morphological zone Blocks
Boundary of zone 4
Block within zone
Qom street network
N
Meters


Legend
Local morphological zone Blocks
Boundary of zone 3
Block within zone
Qom street network
N
Meters


Legend
Local morphological zone Blocks
Boundary of zone 6
Block within zone
Qom street network
N
Meters


Legend
Local morphological zone Blocks
Boundary of zone 5
Block within zone
Qom street network
N
Meters


Legend
Local morphological zone Blocks
Boundary of zone 8
Block within zone
Qom street network
N
Meters


Legend
Local morphological zone Blocks
Boundary of zone 7
Block within zone
Qom street network
N
Meters

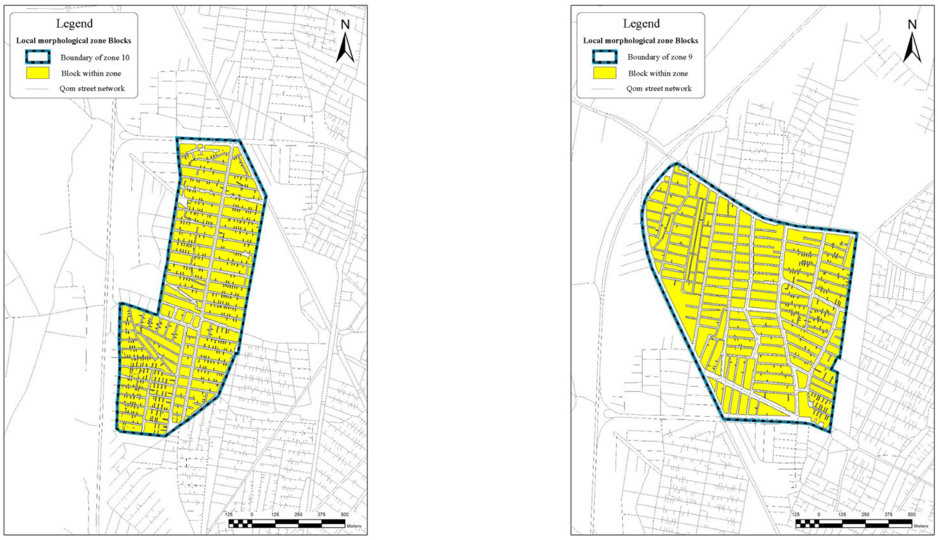


Fig. 8. Block in 10 Local Morphological Zones

Table 1. The Indicators of the Street Layout of the Local Morphological Zones

Indicators of the Street Network Centerline	No	Indicator	Indicators of The Street Network Centerline	No	Indicator
	1	Linear Density of Nodes		16	Relative Dispersion of Link Length
	2	Areal Density of Nodes		17	Areal Density of Link
	3	Ratio of Three-Ways to Total Nodes		**18**	**Areal Density of Link Length**
	4	Linear Density of Three-Way		**19**	**Ratio of Link to Node**
	5	Ratio of Four-Ways to Total Nodes	Indicators of the Blocks	20	Ratio of Total Block Area to Total Zone Area
	6	**Linear Density of Four-Way**		**21**	**Areal Density of Block**
	7	Ratio of Three-Ways to Total Intersections		22	Average Block Area
	8	Ratio of Four-Ways to Total Intersections		23	Standard Deviation of Block Area
	9	Ratio of Dead-Ends to Total Nodes		**24**	**Relative Dispersion of Block Area**
	10	Linear Density of Dead End		**25**	**Average Block Shape Factor**
	11	**Ratio of Three-Ways And Dead-Ends to Total Nodes**		26	Average Block Area-Exchange Index
	12	Ratio of Dead-End to Total Dead-Ends and Cells		**27**	**Average Block Orientation**
	13	Ratio of Cells to Total Dead-Ends and Cells		**28**	**Average Block Orthogonality**
	14	Average Link Length		29	Ratio of Network Area to Total Zone Area
	15	Standard Deviation of Link Length		**30**	**Ratio of Block Area to Network Area**

Table 2. The Descriptive Statistics of the Selected Indicators of the Street Network Pattern of the Local Morphological Zones

Indicator	Number of Zones	Range	Minimum	Maximum	Average	Standard Deviation
Linear Density of Four-Way	10	1.9	0.4	2.3	1.5	0.5
Ratio of Three-Ways and Dead-Ends to Total Nodes	10	0.11	0.88	0.99	0.93	0.03

Indicator	Number of Zones	Range	Minimum	Maximum	Average	Standard Deviation
Areal Density of Link Length	10	0.11	0.03	0.41	0.36	0.04
Ratio of Link to Node	10	0.21	1.06	1.28	1.18	0.07
Areal Density of Block	10	1.12	0.91	2.03	1.42	0.32
Relative Dispersion of Block Area	10	0.97	0.85	1.55	0.89	0.27
Average Block Shape Factor	10	0.08	0.38	0.46	0.41	0.03
Average Block Orientation	10	0.21	5.77	5.98	9.88	6.6
Average Block Orthogonality	10	0.21	0.67	0.88	0.82	0.06
Ratio of Block Area to Network Area	10	2.59	2.01	4.60	2.91	0.82

3.4. The Analysis of the Relationship between the Street Network Centrality and Layout Pattern of the Local Morphological Zones

In order to evaluate the relationship between the layout pattern and the street network centrality on the scale of the local morphological zones, the correlation analysis (by Pearson correlation coefficient) as the method, and SPSS software as the tool were used. The correlation coeficients between the indicators of the network layout pattern and the average centrality index, is represented in Table 3, arranged in descending order. Result shows that three indicators of “areal density of link length”, “ratio of three-way and dead-end to node” and “ratio of link to node” have a significant correlation (P-value ≤ 0.01) with the average network centrality index of the zone, in the way that the first and second indicators have a direct correlation, and the third indicator has an inverse correlation.

Table 3. The Correlation between the Indicators of the Street Layout Pattern and the Average Centrality Index of the Zones

Street Layout Pattern Index	Pearson Correlation Coeficient with the Average Centrality Index of the Zone
Areal Density of Link Length	0.805
Ratio of Three-Way and Dead-End to Node	0.785
Ratio of Block Area to Network Area	0. 510
Average Block Shape Factor	0.311
Average Block Orientation	0.165
Relative Dispersion of Block Area	-0.043
Linear Density of 4-Way	-0.310
Areal Density of Block	-0.376
Average Block Orthogonality	-0.560
Ratio of Link to Node	-0.929

4. DISCUSSION AND FINDINGS

After the evaluation of the layout patterns indicaters and analyzing their relationship with the network centrality indices, the conclusion of the findings resulted from the correlation analysis shows that only three indicators out of 10 indicators of the street layout pattern have a significant correlation (P-value ≤ 0.01) with the average network centrality index (Table 3). The interpretation of the findings is as follows:

- All the three mentioned indicators are network centerline indicators, therefore, the average centrality index does not have a significant correlation with the block indicators.
- The positive, high, and significant correlation between the areal density of the link length with the average local closeness centrality index of the zone street network shows that one of the solutations to increase the network centrality is to increase the longitudinal cover of the network at the considered zone.
- The positive, high, and significant correlation between the ratio of the number of three-way intersections and dead-ends to total nodes (i.e., three-way, four-ways, and dead ends), and negative, high, and significant correlation of the ratio of link to node with the average network centrality index shows the lower average degree of nodes (i.e., the ratio of the number of links branching from nodes) in a zone, the higher the network centrality of that zone. In other words, what causes the value of the local closeness centrality index to increase is the increase in the number of nodes (redirection steps) with a minimum increase in the number of the links, the solution of which is to increase the three-way intersections. By adding each three-way to the network

graph, two nodes and two links are added to the graph, therefore, by increasing the number of three-ways, gradually decreases the ratio of link to node.

The current study analyzed the relationship between the pattern and network centrality on the local scale by studying and analyzing the street layout patterns and explaining the relationship between the stated patterns and the local closeness centrality of the street network from a new perspective and comprehensive attempt. It is noteworthy that in the previous research, studying the network pattern and centrality at the same time has been less considered. The differences and similarities of the current research and the previous studies have been explained as follows. Then, the conclusion has been done in Figure 4.

- The current research studies the network patterns on the local scale based on the different zones of a city in terms of scale and study area. This approach is in line with the studies conducted by MacDougall (2011) and Buzzetti (2017). The study by Strano et al. (2012) has been done in the metropolitan region of Milan (Italy) on the national scale. Louf and Barthelemy (2014) and Rashid (2016) studied the central area of several cities in the world.
- In terms of temporal dimension, the current study has been conducted one-sectional, which is similar to the other mentioned studies except for the study by Strano et al. (2012) that analyzed the gradual transformation of the network n different periods. Hillier (1999) also has introduced network centrality as a process in his study, although he studied the analysis of the network in a single section.
- The current study applied the method of MacDougall (2011) to identify the local morphological zones. Since the purpose of the research conducted by MacDougall was to study the effect of urban edges and urban barriers on the urban form, to study the homogenous zones of the Montreal city, according to him, urban landscape mosaic - has used a detailed study of barriers or impermeable edges and borders or permeable urban edges. This method has also been used in Buzzetti (2017) research.
- In terms of analysis method and modeling of the network centrality, the current study applied the MCA method, which is similar to the study conducted by Strano et al. (2012). However, Hillier (1999), Rashid (2016), and Buzzetti (2017) used the space syntax methods in their studies.
- In terms of analysis and evaluation of the street layout pattern, the current study used statistical and spatial analysis methods. By drawing graphs called square diagrams and node diagrams, Marshall (2005) has provided a graphical method for analyzing and measuring network patterns. MacDougall (2011) also used the statistical analysis (i.e., the distribution graph of the indicators to each other) to analyze the street network. Strano et al. (2012), Louf and Barthelemy (2014), and Buzzetti (2017) also used statistical analysis. Rashid (2016) applied the general statistical analysis method (i.e., one-variable, two-variable, and multivariable) to analyze the network pattern.
- The current study analyzed the street layout pattern in the local morphological zones by applying a wide range of criteria and indicators of two types of street network centerline and blocking. Most of the criteria and indicators were proposed by Marshall (2005), Macdougall (2011), Strano et al. (2012), Louf and Barthelemy (2014), Buzzetti (2017). Marshall (2005) allocated a chapter of his book for identifying and investigating the network pattern and applied the indicators of the network centerline to analyze the network patterns. On the other hand, Louf and Barthelemy (2014) and Buzzetti (2017) used the indicators and criteria of blocking. Rashid (2016) also conducted an extensive study on the layout pattern of the street network by measuring the metric, topological and fractal indicators related to the street network centerline map, block map, axial map, and link map.

Table 4. Comparison between the Current Study and the Previous Studies

Research	Scale and Study Area	Temporal Dimension	Centrality Analysis Method	Network Pattern Analysis Method	Type of Indicators
Current Study	Various Zones of a City	Cross-Sectional	MCA	Spatial and Statistical	Block Network Centerline
Hillier (1999)	Various Centerlines of the City	Cross-Sectional	Space Syntax	Spatial	Network Centerline
Marshall (2005)	Urban Zones (without any Specific Urban Area)	Cross-Sectional	-	Graphical	Network Centerline
Macdougall (2011)	Various Zones of the City	Cross-Sectional	-	Statistical	Network Centerline, Block
Strano et al. (2012)	Metropolitan	Longitudinal	MCA	Statistical	Centerline, Network, Block
Louf & Barthelemy (2014)	Various Central Areas of the Cities	Cross-Sectional	-	Statistical	Block
Rashid (2016)	Various Zones of a City	Cross-Sectional	Space Syntax	Statistical	Block
Buzzetti (2017)	Various Zones of a City	Cross-Sectional	Space Syntax	Statistical	Block

5. CONCLUSION AND RESEARCH RECOMMENDATIONS

To achieve the research purposes, which was explaining the relationship between the layout pattern and the urban street network centrality on the local scale, after modeling the local closeness centrality index and evaluating the street layout pattern in the local morphological zones of Qom city, the relationship between the network pattern and centrality was conducted. Eventually, given the interpretations resulted from analyzing the correlation between the indicators of the layout pattern and the local closeness centrality of the urban street network in the considered zones, it is concluded that:

- To analyze the relationship between the street layout and local closeness centrality of the urban street network, it is recommended to employ the centerline-based indicators of the network; the mentioned claim is justifiable, since centrality index is inherently network centerline-based.
- The more the length of the network at the local fabric and the proportion of the three-way intersections, the more the mean of the local closeness centrality of the links of the street network. Therefore, a more centralized fabric at the pedestrian access will be obtained.

The results of this research can be used in organizing and designing the street network and planning the land use and traffic of the local context to achieve the goals of neighborhood planning in the field of distribution of land uses and management of traffic movement, especially pedestrian movement; Thus, in designing the network of neighborhoods of the city, by increasing or decreasing the density of the link length at the level and number of intersections, the centrality of the network can be increased or decreased, and the presence and intensity of commercial and service activities and pedestrian traffic can be managed.

Regarding the limitations of the present study, we can point to the difficulty of working with big data due to the need for preparation and updating, and analysis and modeling of high volume layer of Qom street network, and network modeling problems with MCA software package due to software complexity. Finally, according to the background and results of the present study, the following suggestions are presented for further research:

- Similar researches on the street layout patterns and also modeling the centrality of the network for other cities of Iran and comparing the findings in order to prepare a detailed model of the street network of Iranian cities;
- The simultaneous use of the primal and secondary approaches for modeling the street network of Qom city and comparative analysis of the results;
- Studying the centrality of the street network of Qom city considering the city development over time and the gradual evolution of the street network and analysis of the movement and change in the form of the routes and the central zones of the city over time.

END NOTE

1. In mathematics and computer science, a graph is a mathematical structure used to model two-way communication between objects. Each graph consists of a set of points or nodes and edges or lines that connect two points. Each communication network can be represented as a graph. Figure 1 shows a graph consisting of five nodes and five edges. If any point on the graph is accessible from all other points, the graph is called connected. For example, the urban street network is interconnected graphics (Freeman, 1979, pp.217-218).

REFERENCES

- Buzzetti, J. (2017). Street Network Morphologies: On the Characterization and Quantification of Street Systems. A Case Study in Montréal. Concordia University. https://spectrum.library.concordia.ca/982414/
- Dempsey, N., Brown, C., Raman, S., Porta, S., Jenks, M., Jones, C., & Bramley, Glen. (2010). Elements of Urban Form Dimensions of the Sustainable City (21-51). Springer. https://link.springer.com/chapter/10.1007/978-1-4020-8647-2_2
- Freeman, L.C. (1979). "Centrality in Social Networks Conceptual Clarification". *Social Networks*, 1(3), 215-239. https://doi.org/10.1016/0378-8733(78)90021-7
- Hillier, B. (1996). Space Is the Machine: A Configurational Theory of Architecture. Cambridge University Press. Cambridge. https://discovery.ucl.ac.uk/id/eprint/3881
- Hillier, B. (1999). "Centrality as a Process: Accounting for Attraction Inequalities in Deformed Grids". *Urban Design International*, 4(3-4), 107-127. https://doi.org/10.1057/udi.1999.19
- Hillier, B., & Hanson, J. (1984). The Social Logic of Space. Cambridge University Press. Cambridge.
- Hillier, B., Penn, A., Hanson, J., Grajewski, T., & Xu, J. (1993). "Natural Movement-or, Configuration and Attraction in Urban Pedestrian Movement". *Environ Plann B*, 20(1), 29-66. https://doi.org/10.1068/b200029
- Louf, R., & Barthelemy, M. (2014). "A Typology of Street Patterns". *Journal of The Royal Society Interface*, 11(101), 20140924. https://doi.org/10.1098/rsif.2014.0924
- MacDougall, K. (2011). The Urban Landscape Mosaic, Assessing Barriers and Their Impact on the Quality of Urban Form: A Montreal Case Study. Concordia University. https://spectrum.library.concordia.ca/35895/
- Marshall, S. (2005). Streets & Patterns. Spon. London ; New York. https://books.google.com/books?id=6rBFKX-3MmcgC&dq
- Mehaffy, M.W., Porta, S., & Romice, O. (2015). "The "Neighborhood Unit" on Trial: A Case Study in the Impacts of Urban Morphology". *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 8(2), 199-217. https://doi.org/10.1080/17549175.2014.908786
- Newman, P., & Kenworthy, J. (1999). Sustainability and Cities: Overcoming Automobile Dependence. Island Press. https://books.google.com/books?hl=en&lr=&id=pjatbiavDZYC&oi=fnd&pg=PR13&dq
- Penn, A., Hillier, B., Banister, D., & Xu, J. (1998). "Configurational Modelling of Urban Movement Networks". *Environment and Planning B-Planning & Design*, 25(1), 59-84. https://doi.org/10.1068/b250059
- Perry, C.A. (1929). "The Neighborhood Unit: A Scheme of Arrangement for the Family-Life Community Regional Plan of New York and Its Environs". New York: Arno Press. 3(4-5).
- Porta, S., Crucitti, P., & Latora, V. (2005). "The Network Analysis of Urban Streets: A Primal Approach". arXiv preprint physics/0506009. https://doi.org/10.1068/b32045
- Porta, S., Crucitti, P., & Latora, V. (2006). "The Network Analysis of Urban Streets: A Dual Approach". *Physica A: Statistical Mechanics and its Applications*, 369(2), 853-866. https://doi.org/10.1016/j.physa.2005.12.063
- Porta, S., Latora, V., & Strano, E. (2010). Networks in Urban Design. Six Years of Research in Multiple Centrality Assessment Network Science (107-129). Springer. https://doi.org/10.1007/978-1-84996-396-1_6
- Porta, S., Latora, V., Wang, F., Rueda, S., Cormenzana, B., Càrdenas, F., Latora, L., Strano, E., Belli, E., Cardillo, A., Scellato, S., Rabino, G., & Caglioni, M. (2009). "Correlating Densities of Centrality and Activities in Cities: The Cases of Bologna (It) and Barcelona (Es)". https://strathprints.strath.ac.uk/18474/
- Porta, S., Strano, E., Iacoviello, V., Messora, R., Latora, V., Cardillo, A., Wang, F., & Scellato, S. (2009). "Street Centrality and Densities of Retail and Services in Bologna, Italy". *Environment and Planning B: Planning and design*, 36(3), 450-465. https://doi.org/10.1068/b34098
- Rashid, M. (2016). The Geometry of Urban Layouts: A Global Comparative Study. Springer. https://link.springer.com/book/10.1007%2F978-3-319-30750-3
- Reneland, M. (2000). "Accessibility in Swedish Towns". Achieving Sustainable Urban form. E & FN Spon, Taylor & Francis Group, London. 131-138. https://books.google.com/books?hl=en&lr=&id=cO_BWyZx8P4C&oi=fnd&pg=PA131&dq
- Strano, E., Nicosia, V., Latora, V., Porta, S., & Barthélemy, M. (2012). "Elementary Processes Governing the Evolution of Road Networks". Scientific Reports. 2. https://doi.org/10.1038/srep00296
- Taylor, J. (1997). Introduction to Error Analysis, the Study of Uncertainties in Physical Measurements. https://books.google.com/books?id=ypNnQgAACAAJ&dq

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