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Exploring the Urban Form of Qom (Iran) at the Local Scale: Movement-Activity Pattern versus Network Centrality

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Abstract

Structural features of the street network - as the intersection of two systems of movement and activity - strongly influence the pedestrian/motorized traffic flow and the distribution of commercial/service (CS) activities throughout large cities. Qom, a large old city in central Iran with a diverse typology of urban form in the historic, middle and peripheral areas, encounters a serious conflict between the functions of the two systems following recently road constructions and increasing automobile dependence. To take a step towards addressing the problem, this paper aims at in-depth explaining the relationship between the street network centrality and the patterns of street layout and CS activity locations in Qom at the local scale of the street network micro-structure, through adopting a quantitative approach by utilising an integration of spatial and statistical tools/techniques. Firstly, ten morphologically-homogenous high-centralised superblocks - called local morphological zones (LMZs) – which are identified through modelling street network centrality index of local closeness (LCNC) using Multiple Centrality Assessment (MCA), are classified employing hierarchical cluster analysis, regarding the street layout and CS activity location patterns by analysing topological/geometrical indicators. Secondly, the relationship between LCNC and the patterns are investigated using Pearson's correlation coefficient and Lorenz curve. The findings reveal that the LMZs' patterns of CS activity locations can be obviously classified into two clusters (the older and newer LMZs mostly stand in two different clusters) while regarding the street layout, the LMZ within the city's historic core stands alone in a cluster; moreover, average LCNC of the LMZs have no significant correlation with indicators of activity location in comparison with the significant correlation with three indicators of street layout pattern, while at the micro-level of the LMZs, CS activity distribution alongside street network segments has more relationship with LCNC compared with the street nodes.

Keyword: *Street Layout, Commercial/Service Activities, Network Centrality, Pattern Classification, Correlation*

Introduction

The street network is one of the main constituent elements of the urban form which requires considerable attention due to its structural role in the city as the intersection of two systems of movement and activity. Human activity takes place in the public spaces which consist of a connective chain of urban streets. Land use is considered as another constituent element of urban form; Public land uses especially commercial and service activities are located alongside the streets since they strongly depend on movement. Hillier believes that such activities situate at live centres to take advantages of movement. Considering Hillier's theory of "movement economy", there are distinct types of spatial configuration that is the result of the notion of "natural movement" (Hillier et al., 1993, Porta et al., 2009, Hillier, 2007, Hillier, 1999). The street layout is the urban street network shape in terms of pattern, structure, and quantitative features, the overall location within the city, and pedestrian and vehicular connectivity which can affect the functionality of a city by influencing the location and intensity of activities (Penn et al., 1998, Porta et al., 2009, Dempsey et al., 2010, Marshall, 2005). The street layout is also one of the most significant factors affecting the centrality of a place. Taking advantage of suitable accessibility, a central place is a special location for living and activity. Suitable accessibility leads to visibility and popularity which are significant factors for the location of CS activities and subsequently improves their efficiency and survival. Thus, centrality emerges as one of the most powerful determinants for urban planners/designers to understand how a city works and to decide where renovation and redevelopment need to be placed (Newman and Kenworthy, 1999, as cited by: Porta et al., 2009).

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 urban streets, as the context of the interference, shows how the improper structure of the street network can disrupt the performance of both systems. As mentioned, the survival of CS activities depends on movement; consequently, the two systems cannot be separated since the existence of such relationship makes urban space lively. Hence, it is necessary to systematically organize the relationship in the city; and the first step is studying and investigating the roots and influential factors. With the goal of explaining the relationship between the street network centrality and movement-activity pattern at the local scale, i.e. the microstructure of the street network, the current paper aims at answering the question that how to explain the relationship between street network centrality index of local closeness (LCNC) and both patterns of street layout and CS activity locations in Qom to address the problems resulting from interference between the two systems. Qom city is one of the old cities of Iran that has a unique urban fabric in the central core of the city and a variety of the street layout in the middle and peripheral parts. Therefore, this city provides a suitable case for exploring the movement-activity patterns. The research findings would be useful for urban authorities in future planning and design.

Quantitative Analysis of Urban Form

The current research explains the relationship of the LCNC with both patterns of street layout and CS activities by the use of objective data and quantitative methods. Regarding different studies has been done with a variety of viewpoints, this research is based on an objective-structural viewpoint to urban form. Dempsey et al. (2010) consider five constituent elements for urban form: density, housing/building type, layout, land use, and transport infrastructure. The current research investigates two elements of land use and layout. In this section, the methods employed for the data analysis in the current paper are presented.

Methodology for Modelling Network Centrality

There are four main indices of network centrality, namely, closeness, betweenness, straightness and information (Porta et al., 2005). Considering the aim and the scale of the current research, the local closeness centrality index (LCNC) is used for measuring street network centrality. The closeness centrality index measures to what extent a node is close to all other nodes along the network geodesics. Regarding two main approaches for analysing and modelling the urban street network as a graph, i.e. the primal approach and the dual, the current study employs the former. Opposite to the dual approach of the Space Syntax method, Multiple Centrality Assessment (MCA) is a more recent method for the network analysis of centrality in geographic systems such as urban street network that follows primal approach to metrically analyse urban street network centrality regarding its four indices (Hillier and Hanson, 1984, Hillier, 2007, Porta et al., 2005, Porta et al., 2006). To calculate LCNC, the analysis radius is considered 400 meters; therefore, the resulting model indicates the central zones in the scale of the neighbourhood unit (Perry, 1929) which also provide appropriate walking/cycling access.

Methodology for Identifying and classifying the Patterns

The current research employs both topological and geometrical approach in identifying the patterns of street layout (to read more: Marshall, 2005, Porta et al., 2005, Hillier, 2007, Rashid, 2016). The topological approach analyses the configuration of the network which is presented as an abstract diagram that deals with the non-metric information of the network structure while the geometrical (metric) approach evaluates the composition of the network which is the geometrical formation of the layout (Marshall, 2005). On the other hand, due to the research aim, some of the Galster's indicators are chosen for identifying the CS activity patterns since they present a well-defined method for assessing land use patterns (Galster et al., 2001). To classify the layout/activity patterns, the agglomerative clustering technique is employed; its output, which is considered as a hierarchical cluster analysis, is a tree diagram (or dendrogram) of clusters. The clusters are successively merged together to reach the final point (Rokach and Maimon, 2005).

Methodology for assessing the relationship between street network centrality and the patterns

To analyse the correlation between the layout/activity pattern indicators and the LCNC, the correlation analysis is employed through calculating simple linear correlation coefficient, i.e. Pearson correlation coefficient. The coefficient between two random variables equals their covariance divided by the multiplication of the standard deviation of each and its value varies between -1 and 1, which indicates the proportionality of the value of two variables to each other. The positive and negative values indicate the direct and inverse relationship between the variables, respectively (Taylor, 1997, as cited by Porta et al., 2009). To analyse the patterns at the micro-scale of the LMZs, the Lorenz curve utilised. The Lorenz curve is used in various disciplines to see whether a particular aspect is equally or randomly distributed. It correlates the accumulative proportion of a factor to that of another (Duclos and Araar, 2007). The Gini coefficient is obtained by dividing the area sandwiched between the line of maximum equality (a line of 45 degrees) and the Lorenz curve by the total area under the line of equality (Mohamed and van Nes, 2017).

Data Analysis and Results

Datasets

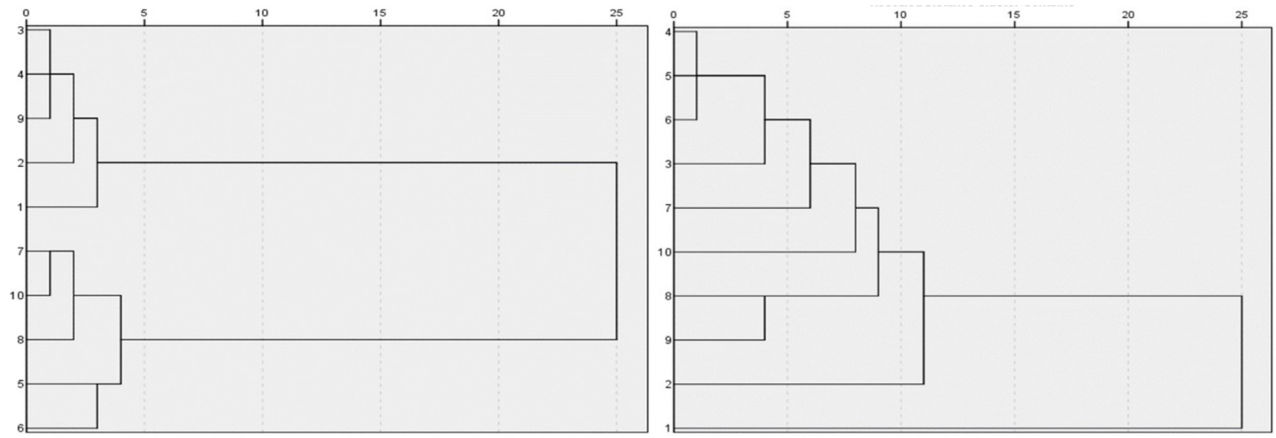
The identification of the patterns of street layout and activity location relies on the georeferenced vectorial datasets of the street network centreline, blocks and CS activity plots. Since the network centrality modelled on the network graph links, modelling LCNC also relies on the dataset of street centreline. The datasets were provided by the Municipality of Qom; the first one dates back to 2016, and the other two ones to 2011, which both have been updated with the changes until 2018. The datasets cover the entire municipal area of Qom.

The Research Process

The assessment process which leads to achieve the research findings is as follows; due to the limitation of the paper length, the first step is not presented in the current paper (to find out more: Zamani, 2019, Zamani et al., 2020): (1.) modelling LCNC of the street network to identify the more centralised areas at the local scale which leads to determining the suitable urban zones, i.e. the urban superblocks which have a considerable average LCNC of street links and are suitable for measuring and evaluating the patterns of the street layout and CS activity at the local scale; (2.) measuring and evaluating the patterns of the CS activity locations in comparison with street layout patterns within the selected central zones; (3.) analysing the relationship between street network centrality of LCNC and the patterns of the street layout and CS activities within the selected central zones. After conducting the step 1, ten final zones are determined as the LMZs that are named numerically based on the ascending order of historical phases of the urban development (Zamani, 2019, Zamani et al., 2020).

Assessment of the morphological patterns of street layout and CS activity locations in the LMZs

According to the research background and aim, and the availability of the spatial data, a comprehensive list of 30 indicators of the street layout pattern (19 for street centrelines and 11 for blocks) and 8 indicators of CV activity location patterns are provided, which are decreased to 10 for street layout (i.e., 4 street centreline and 6 block indicators) and 4 for CV activity locations after eliminating every one of two significantly correlated indicators (at the significance level of 0.01) utilising correlation analysis in order not to over-emphasise on parallel features (to find out more: Zamani, 2019, Zamani et al., 2020). Since the research aim is explaining the relationship inside every LMZ, the marginal activities located on the boundary of the LMZ are excluded from the analysis so that not to deviate the results, since the location selection of marginal activities are mostly based on the movement merit of the corresponding arterial streets or the proposed land uses of the city development plans; and thus, are not related to the layout-activity patterns of the LMZ itself. To analyse the similarities/differences between the morphological patterns of LMZs in terms of street layout and CS activity locations, the method of hierarchical cluster analysis is adopted which leads to building a dendrogram of clusters (Figure 1), while the label of the LMZs are shown on the vertical axis and the inter-LMZs distance are shown on the horizontal axis. The recursive algorithm are applied using Ward's linkage method based on the squared Euclidean distance.



(A) (B)

Figure 1. *(A) Dendrogram of LMZs' clustering based on street layout pattern; (B) Dendrogram of LMZs' clustering based on CS activity location pattern.*

Analysis of the relationship between LCNC and patterns of street layout and activity locations in the LMZs

To evaluate the relationship between the average LCNC of every LMZ and the indicators of the street layout and CS activity location patterns, the correlation analysis (by Pearson correlation coefficient) method are employed. The results are presented in Table 1 while arranged in descending order of the values.

Table 1. Correlation between the indicators of the layout/activity pattern and the average LCNC of the LMZ

	Indicator	Pearson correlation coefficient
Street layout pattern	**Areal density of link length***	**0.805**
	Ratio of three-ways & dead-ends to total nodes*	**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 four-way	-0.310
	Areal density of block	-0.376
	Average block orthogonality	-0.560
	Ratio of link to node*	**-0.929**
CS activity pattern	Clustering of activities	0.227
	Concentration of activities	0.125
	Continuity of activities	-0.166
	Segment density of activities	-0.431

*** Significant at the 0.01 level**

To rigorously explain the relationship between the LCNC and the layout-activity patterns, it is investigated at the micro-level of the LMZs by assessing the distribution of every layout measure of the number of four-ways, three-ways and dead-ends, and the activity location measure of the number of CS activities, alongside the street network segments. The assessment is possible using the Lorenz curve which is performed by calculating the cumulative percentage of the number of the measures - plotted on the y-axis - against the cumulative percentage of the street network segment length arranged in ascending order of the LCNC value - plotted on the x-axis (to find out more: Zamani, 2019). Table 2 shows the resulting Gini Coefficient values.

Table 2. Gini coefficient values of four layout/activity measures among the LMZs

LMZ		1	2	3	4	5	6	7	8	9	10	Average	SD
Gini coefficient	Dead-end	0.20	0.03	0.02	0.05	0.16	0.01	0.15	0.20	0.37	0.07	0.13	0.11
	Three-way	0.05	0.07	0.14	0.11	0.05	0.06	0.14	0.19	0.19	0.02	0.10	0.06
	Four-way	0.23	0.18	0.01	0.17	0.05	0.27	0.17	0.10	0.04	0.25	0.15	0.09
	CS Activity	0.42	0.06	0.26	0.13	0.12	0.21	0.29	0.11	0.35	0.29	0.22	0.11

Findings and Discussion

The results obtained from the hierarchical cluster analysis of the LMZs in terms of the street layout pattern reveals that the LMZ 1, which is located within the historic fabric of Qom, stands lonely within a cluster with a high distance to the other cluster, whenever classifying them into two clusters. This finding demonstrates that the street layout pattern within the historic fabric of the city of Qom possess distinctive characteristics which make it unique. While considering the CS activity location patterns, the results achieved from visual inspecting of the dendrogram indicate that the LMZs are obviously classified into two clusters each containing five LMZs while the older and newer LMZs mostly stands in two different clusters. The results achieved from the correlation analysis can be interpreted as follows: (1.) all three significant correlation values are related to indicators of street centreline (none or which for the blocks). It looks reasonable because the LCNC is modelled on the network links (i.e., centrelines). The positive, high, and significant correlation between the areal density of link length with the average LCNC shows that one of the solutions to increase the LCNC in a central area is to increase the total street length within that area. The positive, high, and significant correlation between the ratio of the number of three-ways and dead-ends to total nodes. The negative, high, and significant correlation of the ratio of link to node with the average LCNC shows that the lower the average degree of nodes (i.e., the ratio of the number of links branching from a node) in a central area in Qom, the higher the LCNC of that area; (2.) regarding the insignificant correlations of the indicators of the CS activity locations with the average LCNC and considering that Zamani et al. (2017) conclude that there is a moderate positive correlation of 0.61 between LCNC and location of activities at the city scale of Qom, while taking into account that the marginal activities are eliminated from the dataset in the current research, it can be interpreted that CS activities in Qom tend to locate along the marginal edge of the central zones more rather than locating within them to take the advantages of high rate pedestrian/motorized movement which lead to more visibility. Furthermore, it is noticeable that all the LMZs have an average LCNC more the mean LCNC of the whole city of Qom. Moreover, considering that the average LCNC has not necessarily direct relationship with the historical phase of development of the LMZs, the finding supports the results of the cluster analysis which show a relationship between the CS activity patterns and the age of the LMZ.

The results achieved from assessing the micro-level of the LMZs by plotting the Lorenz curve demonstrate that the street graph nodes (i.e., dead-ends, four-ways and especially three-ways) have a rather uniform distribution pattern alongside the street network of the LMZs with respect to the LCNC values while the distribution of the CS activities alongside streets is rather uniform but shows more unequal distribution rather than the street nodes in the way that the more proportion of CS activities is situated alongside the more centralised street segments. The Gini coefficient values also show that the CS activities have the highest average while having the lowest degree of standard deviation, accordingly, it is true for most of the LMZs. Compared with the result of correlation analysis, this finding is noticeable that the location of the CS activities have more relationship to the LCNC of street network segments rather than the average LCNC of the LMZ.

Conclusion and Research Recommendations

To achieve the research aim, which is explaining the relationship between the layout-activity patterns and the network centrality at the local scale, the following main steps is done: (1.) modelling the LCNC in the LMZs, (2.) the hierarchical cluster analysis for classifying the patterns, (3.) analysing the correlations between the pattern indicators and average LCNC as well as assessing the Lorenz curve to indicate the distribution of the pattern elements alongside the street network segments considering the value of the LCNC. Ultimately, given the interpretations resulted from analysing the results, it is concluded that: (1.) the historic fabric of the city of Qom possess distinctive street layout pattern which make it unique. Opposite to LCNC, CS activity location patterns show some relationship with the age of the LMZs; (2.) to analyse the relationship between the street layout and the LCNC of the urban street network, centreline-based indicators must be applied. The more the length of the network at the local fabric and the number of the three-way intersections, the more the average LCNC of the links of the street network; and thus, a more centralized fabric at the scale of pedestrian access will be obtained; (3.) the location of the CS activities have more relationship to the LCNC of street network segments rather than the average LCNC of the LMZ. The number of CS activities shows quite an increase with the increasing of the LCNC of the corresponding street segments. The results can be used in designing the street network and planning the land use and traffic to achieve the goals of neighbourhood planning. Finally, the following suggestions are presented for further research: (1.) similar researches on morphological patterns of other Iranian cities to prepare a detailed model of the Iranian city form; (2.) a longitudinal study of the movement-activity patterns in Qom city.

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References

1. Dempsey, N., Brown, C., Raman, S., Porta, S., Jenks, M., Jones, C. & Bramley, G. 2010. Elements of urban form. Dimensions of the sustainable city. Springer.
2. Duclos, J.-Y. & Araar, A. 2007. Poverty and equity: measurement, policy and estimation with DAD, Springer Science & Business Media.
3. Galster, G., Hanson, R., Ratcliffe, M. R., Wolman, H., Coleman, S. & Freihage, J. 2001. Wrestling sprawl to the ground: defining and measuring an elusive concept. Housing policy debate, 12, 681-717.
4. Hillier, B. 1999. Centrality as a process: accounting for attraction inequalities in deformed grids. Urban Design International, 4, 107-127.
5. Hillier, B. 2007. Space is the machine: a configurational theory of architecture.
6. Hillier, B. & Hanson, J. 1984. The social logic of space, Cambridge, Cambridge University Press.
7. 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, 29-66.
8. Marshall, S. 2005. Streets & Patterns, London ; New York, Spon.
9. Mohamed, A. & Van Nes, A. 2017. Spatial accessibility and commercial land use patterns planned versus unplanned areas in Cairo.
10. Newman, P. & Kenworthy, J. 1999. Sustainability and cities: overcoming automobile dependence, Island Press.
11. Penn, A., Hillier, B., Banister, D. & Xu, J. 1998. Configurational modelling of urban movement networks. Environment and Planning B-Planning & Design, 25, 59-84.
12. 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, 5.
13. Porta, S., Crucitti, P. & Latora, V. 2005. The network analysis of urban streets: a primal approach. arXiv preprint physics/0506009.
14. Porta, S., Crucitti, P. & Latora, V. 2006. The network analysis of urban streets: a dual approach. Physica A: Statistical Mechanics and its Applications, 369, 853-866.
15. Porta, S., Latora, V., Wang, F., Strano, E., Cardillo, A., Scellato, S., Iacoviello, V. & Messora, R. 2009. Street centrality and densities of retail and services in Bologna, Italy. Environment and Planning B: Planning and design, 36, 450-465.
16. Rashid, M. 2016. The Geometry of Urban Layouts: A Global Comparative Study, Springer.
17. Rokach, L. & Maimon, O. 2005. Clustering methods. Data mining and knowledge discovery handbook. Springer.
18. Taylor, J. 1997. Introduction to error analysis, the study of uncertainties in physical measurements.
19. Zamani, V. 2019. Morphological analysis of movement-activity pattern of urban fabric with the emphasis on street network centrality; case study: Qom, Iran. Ph.D., Art University of Isfahan, Isfahan, Iran.
20. Zamani, V., Ghalehnoee, M. & Mohammadi, M. 2020. Exploring the Microstructure of the Urban Street Network: Layout Pattern Versus Centrality. Armanshahr Architecture & Urban Development, 13.
21. Zamani, V., Mohammadi, M. & Ghalehnoee, M. 2017. Exploring the relationship between street network centrality and location selection of commercial and service activities in Qom city.