Quantitative Analysis of Urban Streets Based on Network Connectivity

Yan Xiao, Daye Wu, Zehui Li, and Bingxin Wang

***Abstract*—As the most important material carrier in urban space, street plays an important role in the formation of urban form. The description and analysis of street spatial form by traditional methods are mostly limited to a single spatial attribute, which is difficult to touch the complex coordination and evolution mechanism among the components of street spatial network system. Based on the complex network theory, this paper adopts the Space Syntax and Routegram to carry out quantitative analysis of urban street spatial network connection. Taking full account of the spatial characteristics and topological structure of streets, the research framework of urban street network connectivity was established, and the urban street spatial network comprehensive analysis method was constructed.**

***Index Terms*—Urban street, spatial topological structure, semi-lattice topological structure, topological network structure, spatial network, space syntax.**

I. Definition of Relevant Concepts

The research subject of this paper is "street networks", the concept of which should be collectively determined by the concepts of "streets" and "networks".

A. Urban Street

A Street can be regarded as a road that happens to possess city attributes, or as a city place that bears the functions of a road [1]. Before elaborating the concept of streets, it is necessary to simply distinguish the concepts of "streets" and "roads": "roads" refer to the paths that traffic runs through, emphasizing the traffic nature; while in contrast, "streets" bear more functions of urban life, and meanwhile, the major feature of streets is that they can provide relatively clear spatial cognition for citizens [2]. Generally speaking, the constituent elements of traditional urban streets include traffic paths, public space and roadside building areas [3]. To tell the difference between the concepts of streets and roads has the following impacts on the research:

First of all, roads that only have traffic paths but no public space cannot be referred to as streets, such as elevated expressways which are not included as a part of the street networks in this study. However, it does not mean that elevated expressways will not be studied at all in subsequent research, as the emergence of elevated expressways has changed the original structure of street networks [4]. Therefore, there actually is need to study elevated expressways although they do not belong to the same network as streets. Secondly, even though expressways are excluded, the concept of "streets" in the street network samples of the research does not completely overlap with that of roads. In the thoroughly open public urban space, the paths inside will be included in the street networks as part of the research subject, such as the numerous paths on the Versailles Palace Square in Paris, which are totally connected with the other streets in the city. Finally, technically, street is a three-dimensional concept which includes not only the horizontal plane of the streets, but also the roadside plane of the buildings. Consideration the limitation of the present study, the three-dimensional space of streets is not investigated in this paper. However, the street sections selected in this study are the plane space between the buildings on both sides of the road, and the marginal line of the land will be selected if there is no building frontage.

B. Spatial Network

A network comprises of numerous nodes and the lines linking them together, which represents multiple subjects and their interconnections [5]. Before 1999, people generally thought that the structure of networks was random. However, after the scale-free properties and small-world effect of networks were discovered and published [6], people started to realize the complexity of networks. To take "street networks" as a research subject is to mediate the phenomenon of scale extramalization in urban street studies. For instance, the studies of traditional phenomenologists usually focus on the spatial experience of individuals in individual city streets. This kind of studies is of great significance to the cognition of individual street space [7]. However, it has ignored that a city exists as an integrated whole. On the contrary, in the field of urban geography or transport research, people tend to study a city as a pure macroscopic mathematical model, and the relevant conclusions are usually too modeling and mathematical to correspond to the realistic spatial cognition [8]. Actually, despite that the cognition of an individual about the city is integral in the brain, it is not a systematic cognition that forms at one time. Instead, it is actually an experience set of people's cognition about each individual part of the city [9]. That is to say, people's cognition about a city is formed by their cognition about each single part of the city and the organizational relationship between these cognitions on a gradual basis. Therefore, the study on cities is eventually a study on how parts form a complex whole [10].

According to the cognitions about individuals and the whole in a city mentioned above, it can be seen that the research on streets should not be limited to the scale of local

Manuscript received January 10, 2019; revised April 24, 2019. This work was supported in part by the China Postdoctoral Science Foundation (Grant No.: 2016M600203).

Yan Xiao is with the School of Architecture and Fine Art, Dalian University of Technology, Dalian, China (e-mail: xiaoyan@dlut.edu.cn).

Daye Wu, Zehui Li, and Binxin Wang are with the Dalian University of Technology, Dalian, China (e-mail: wudaye19981209@mail.dlut.edu.cn, lzh57210@mail.dlut.edu.cn, wbxdlut@gmail.com).

doi: 10.18178/jacn.2019.7.1.264

space [11]. Instead, a relatively complete space system should be selected as the sample. The major element that can bear the holistic structural cognition of the city is its street networks. Each element of the city is connected with each other through the street network so as to form an integral system. The integral structure of streets is able to express the interconnection of each spatial component in a city [12]. Besides, the research of urban space is essentially the research of its connection patterns. Therefore, through the study on the street network of a city, people can understand the urban structure, realize the relationship between the pattern and spatial experience of the city, and analyze the connotation of urban space on a higher level.

II. Quantitative Analysis of Streets Based on Structure of the Network

With Space Syntax and Routegram analysis tools, this paper identifies that the research framework of the connectivity of urban street networks includes two subsystems of urban street networks, that is, the spatial topological form and structure properties, thus constructing an empirical analysis technical path for the comprehensive analysis of urban street spatial networks.

A. Integration Analysis of the Topological Form

As two independent and mutually supplementary spatial analysis methods, Space Syntax and Routegram analysis adopt different segmentation of space units. Nevertheless, these two spatial analysis models have similar integral space construction logic. Both the spatial axis diagram and path structure diagram quantitatively describe and analyze the relationship between the local and global spatial elements in the spatial pattern and structure with graph theoretic approaches from a topological perspective, exploring how spatial elements form a holistic topological structure via their interrelation.

Although the Space Syntax and Routegram are both the topological structural products of interrelation patterns of spatial topological elements, these two methods are developed based on different topological properties. The formation mechanism of Space Syntax diagram excludes spatial geometric properties, and uses lines to represent convex and uses the connection between the lines to represent the connection between the convex spaces, thus converting the spatial structure into a spatial axis diagram [13]. This method of representation pierces through all the graph spaces with the longest and fewest axis in the process of its establishment. Therefore, the formation of the axis is mathematically unique in theory; as for the latter, the formation of its path structure diagram, the multiple alternatives of link paths across the paths [14], which correspond to different path structures, give rise to the diversified expressions of the path structure [15]. Therefore, during the formation of the path structure diagram, it is necessary to limit and determine the path schema based on the spatial information of the research subject, including factors like road grade, road width, road bearing mode etc. It can be seen that the different emphases of these two different spatial analysis methods have, to some extent, resulted in their respective advantages and limitations as research methods.

This paper is to combine the axis analysis of Space Synta and path structure analysis of Routegram to comprehensively analyze the urban street spatial network. Compared with the single research method that simply focuses on the spatial topological form or path structural properties, the research that integrates these two spatial analysis methods is going to achieve an integration study on the geometric form, topological form, path structures and other spatial properties of urban streets.

B. Quantitative Measurement of Urban Street Topological Form

Two common parameters of Space Syntax are applied to the comprehensive analysis of urban street spatial networks.

1) Integration

Since the quantitative calculation method of the depth value heavily relies on the number of vertices in the space system, the s Space Syntax theory proposes the concept of integration value to prevent the interferences caused by the vertex and unit numbers in the space system, which is used to map the aggregation or dispersion degree of a vertex or a unit in the space system with the whole space of the system. In a certain space system, when all vertices or units are closely adjacent, the integration value of this system is high; in contrast, when the vertices or units stay far away from each other and lack interconnection, the integration value of the space is low [14]. The comprehensive definition formula is as follows:

$$RA_i = \frac{2(\overline{D_i} - 1)}{n - 2} \tag{1}$$

2) Intelligibility

According to the Space Syntax theory, individuals need to observe and experience the urban space system in a dynamic way, only by which can they construct the macroscopic picture of the urban space system from part to whole. Intelligibility is to weigh the local space structure observed in independent single space, and meanwhile evaluate whether a single space is helpful to the construction of the picture that includes the entire space system, that is, whether it can be used as an index to capture the whole space structure. Intelligibility can be used to describe the correlation degree between this kind of local variables and global variables. Therefore, space that has both high connectivity value and high integration value can be regarded as a space system with high intelligibility. Intelligibility records the extent to which the local space is correlated to and coordinated with the global space. In a space, if the vertices have relatively high connectivity value and integration value within a local range, it means that this space system is clearly layered and highly comprehensible, so this space is sure to have relatively high intelligibility. High intelligibility means that the space experiencers can perceive the entire space through some local parts of the space more easily, and that local parts are more likely to form personalized space; in contrast, low intelligibility suggests the lack of personalized space, and it also means that it is hard to form a good spatial entirety and meanwhile the parts cannot be well commanded by the whole. Essentially, intelligibility reflects the degree of difficulty for individuals to acquire holistic experience of the entire pace based on the spatial connectivity within a local range [14]. The comprehensive definition formula is as follows:

$$R=\frac{\delta_{i_n i_3}}{\delta_{i_n}\delta_{i_3}}=\frac{\sum(I_n-\overline{I_n})(I_3-\overline{I_3})}{\sqrt{\sum(I_n-\overline{I_n})^2}\sqrt{\sum(I_3-\overline{I_3})^2}} \tag{2}$$

C. Diagram Measurement of Urban Street Structure

As a physical space, the urban space has a certain area, a clear range and boundaries, and can be drawn on a map. Therefore, in addition to the measurement of parameter quantification, diagrams can also be used to describe the properties of the path structure as well as the location relation, distance relation and coupling relation of the vertices in the space. This paper applies the Routegram proposed by Marshall to analyze the structural properties of the street space, extending the numerical relationship in the connotation of the space analysis models to vector quantity.

As in Fig. 1, the Routegram has established a brand-new attribute diagram, including the Netgram and the Hetgram. These two diagrams analyze space systems from a respective of street networks and street pattern characteristics, respectively. These two triangle diagrams can be established with the values of all the six attribute characteristics of the studied space. Any random point in the two diagrams above follows either the equation or any point in the Routegram can be described using the three or even two of the parameters. Based on the diagram drawing principles above, specific auxiliary lines and reference points can also be drawn in the diagram, so as to identify and measure the characteristic points in the diagrams [15].

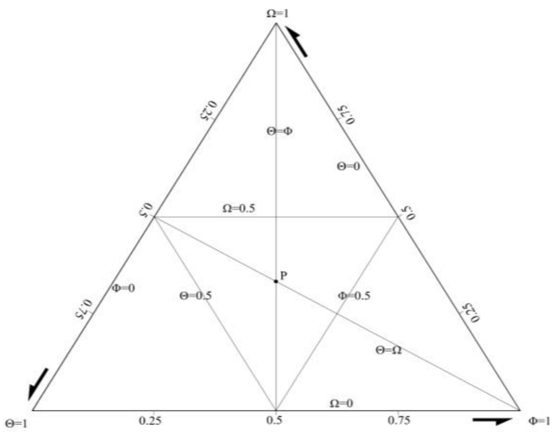

Fig. 1. Routegram diagram.

III. Empirical Study

To further explore the mechanisms of the formation and mutual interference between space's topological form and functional structure, it is necessary to select proper urban sections as the research space samples. This study selected 9 urban sections in city of Dalian, and used the comprehensive analysis method of street spatial networks to explore the evolution processes and formation mechanisms of the topological form and functional structure of the urban street network, as well as to investigate ways to restore the complexity and vitality of urban streets.

A. Research Samples

As the central city in the northern coastal areas of China, Dalian is located in hilly areas, forming a banded cluster structure around natural mountains. In addition, because of some historical reasons, Dalian possesses and has relatively completely maintained the urban forms of different colonial periods of both Japan and Russia, forming the unique colonial urban pattern and form, that is, the urban form of coexistence of Baroque axis system and chessboard system, which has provided abundant and diversified empirical research materials for this study.

In order to ensure that the space samples are able to correctly reflect the overall situation of the space matrix and the differences of the samples are adequately demonstrated, the study referred to the following principles when selecting the subjects of the space empirical research. As for the sampling units of each urban section sample, based on the previous analysis of individual walking accessibility evaluation value and accessibility status, this study adopts the walking time limit that one can barely bear, that is, 20 minutes (about 1,200 meters), as the references to determine the boundaries of the space samples. Consequently, the research range of each space sample is determined to be a 1,200m*1,200m rectangle scope, which is taken as the basic unit of the space empirical study.

B. Overview and Characteristics of the Research Samples

First of all, space samples need to be typical and have distinct features in the spatial layout; secondly, space samples need to include as many types of street space and geomorphic features as possible; finally, the selected samples should emerge in different cultural and social contexts, in order to examine the relationship between the formation background of the city and the evolution mechanism of the urban form [17]. Based on the principles above and the model of urban space development types proposed by Marshall, this paper categorizes the space samples into the following types: space samples of historical core zones, space samples of traditional urban development zones, space samples of new urban development zones, space samples of urban fringe zones and space samples of suburban settlement zones, and selects 9 samples of comprehensive urban street sections which integrate various block types within Dalian as the technical empirical objects of the comprehensive space analysis method.

The nine urban local street sections selected in this paper are all closed related to the entire city in terms of the morphological characteristics and functional structure, and these sections are uniformly distributed within Dalian. These sections contain the memories of the city and bear the cultural contexts of the city, so as to create a specific sense of place and identity, forming distinctively characterized urban spaces.

C. Integration Analysis of the Research Samples

The nine urban local space sections selected in this paper include differentiated street spatial patterns and functional structure types. Table I to Table Ⅸ show analysis results of Space Syntax and Routegram.

TABLE I: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF ZHONGSHAN SQUARE AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.0134-1.5057	Θ	0.1467
Global integration（average value）	0.7846	Φ	0.5308
local integration（value domain）	0.0102-3.4574	Ω	0.3291
local integration（average value）	0.6227		
Intelligibility	0.7642		

TABLE II: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF PEOPLE SQUARE AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.5259-2.3067	Θ	0.7832
Global integration（average value）	0.9643	Φ	0.7566
local integration（value domain）	0.8240-3.3775	Ω	0.1897
local integration（average value）	1.4466		
Intelligibility	0.8939		

TABLE III: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF XIAN ROAD AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.7701-2.3127	Θ	1.1036
Global integration（average value）	1.7415	Φ	0.6049
local integration（value domain）	0.6659-3.4872	Ω	0.3102
local integration（average value）	3.3046		
Intelligibility	0.8276		

TABLE IV: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF HUANAN SQUARE AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.4496-2.2482	Θ	0.1785
Global integration（average value）	1.1412	Φ	0.3049
local integration（value domain）	0.6680-3.3398	Ω	0.5370
local integration（average value）	2.2265		
Intelligibility	0.8053		

TABLE V: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF JINMA ROAD AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.4593-1.8915	Θ	0.2201
Global integration（average value）	1.2782	Φ	0.4378
local integration（value domain）	1.4587-2.9173	Ω	0.3205
local integration（average value）	2.264		
Intelligibility	0.8210		

TABLE VI: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF MINZHU SQUARE AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.5203-2.3042	Θ	0.2298
Global integration（average value）	1.1502	Φ	0.3471
local integration（value domain）	0.3541-2.8326	Ω	0.4230
local integration（average value）	1.4179		
Intelligibility	0.8090		

TABLE VII: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF DAHUA ROAD AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.3164-1.2655	Θ	0.1758
Global integration（average value）	0.8436	Φ	0.4492
local integration（value domain）	1.3286-2.6572	Ω	0.3876
local integration（average value）	1.3286		
Intelligibility	0.6946		

TABLE VIII: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF AIRPORT RESIDENTIAL AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.4607-1.3821	Θ	0.2698
Global integration（average value）	0.9214	Φ	0.3785
local integration（value domain）	1.3589-2.7178	Ω	0.3812
local integration（average value）	0.9059		
Intelligibility	0.6118		

TABLE IX: SPACE SYNTAX AND ROUTEGRAM ANALYSIS OF QIXIANLING AREAS

Analysis Results of Space Syntax		Analysis Results of Routegram	
Global integration（value domain）	0.3270-1.9622	Θ	0.2277
Global integration（average value）	0.9811	Φ	0.4065
local integration（value domain）	1.3925-2.7850	Ω	0.3921
local integration（average value）	0.9283		
Intelligibility	0.7708		

IV. CHARACTERISTIC ANALYSIS OF THE RESEARCH SAMPLES

In the following section, quantitative analysis will be conducted on the characteristics of the topologic samples above based on the spatial measure values.

A. Space Integration Analysis

According to the integration diagram of the space samples, it can be seen that the integration values of the areas of People's Square, Zhongshan Square and Xi'an Road with Chessboard Street layouts are relatively high, which can provide flexible and diversified route options. At the same time, connected streets and a large number of traffic nodes have also formed various forms of loops, guaranteeing the accessibility and continuous diversity of space. Among these areas, the road system in the Zhongshan Square section is a combination of chessboard and radial road systems, and the peaks of its integration value are concentrated in the several radial lines that connect the right-angle blocks, which are the central axes of the entire area. In contrast with the chessboard road system, the road systems in the fringe and suburban settlement areas of the airport new district, Qixianling, Jinzhou Democracy Square and Dahua Street, Lvshun clearly have lower levels of integration and connectivity. The reason is that most of these road systems with tree-like features serve their respective main systems and are mutually supplementary, and the traffic needs to run between different topological levels through branches and loops in a unidirectional manner; as a combination of differently characterized streets, the areas of Nanhua and Jinma Road have semi-tree-like and semi-chessboard structural characteristics, with relatively vague road grade division. Therefore, the integration values of these areas lies between those of the tree-like and chessboard space samples, presenting medium-level space accessibility. Despite that the space samples of traditional and new urban development zones have similar hybrid road topological structures, the integration value of the traditional urban development zones is still lower than that of the new urban development zones, which reflects that compared with the traditional urban street topology, modern urban streets are more suitable for the arrival and crossing of traffic flows when the vehicle flow is small, and this characteristic can also be verified in practice.

B. Space Intelligence Analysis

According to the intelligence values of the space samples above, it can be seen that the intelligence value of the urban fringe areas is relatively low, and in contrast, the samples with chessboard layout have relatively high intelligence values, and the intelligence values of other space samples mostly lie between the thresholds of the previous two. Without overall and uniform planning, the local topological structure characteristics of the space sample of suburban areas do not show continuity with the entire section. Therefore, individuals cannot capture the entire structure of the space through the obtained cognitive information about a particular local space. In contrast, in the chessboard street layout, each local area is similarly constructed, thus forming an integrated whole. Taking People's Square as an example, this place was built during the Japanese colonial period in a typical chessboard pattern, with an intelligence value of up to 0.9. In this kind of spatial form, the local and global cognitions of an individual about the space are continuous and synchronous, that is, individuals are able to perceive the morphological structure of the entire space through the space's local sections. Unlike the chessboard space samples, which have homogenous and continuous topological structures, hybrid street space samples still have an overall intelligence higher than that of the urban fringe areas though.

C. Diagram Analysis

According to the Table I to Table Ⅸ, it can be seen that the heterogeneity representation nodes of all space samples are distributed on the right side of the midline within the triangle diagram, and the distribution range decreases from complexity to regularity. Among them, the heterogeneity representation nodes of the historical core zones and the space samples with chessboard layout are closer to the line of the triangle, while those of the space samples of the urban fringe and suburban settlement zones are relatively closer to the midline. This means that compared with the former, the latter has the characteristic of stronger network recursiveness. The recursive parameters of all space samples in this study are lower than 0.4, which means that high resursiveness is quite rare in real urban space and much more common in theory. Among these space samples, the sample spaces with a chessboard street layout represented by People's Square are distributed in the lower half of the triangle, demonstrating relatively low complexity eigenvalues; while the overall complexity degree of the urban fringe areas with tree-like structures is relatively higher than that of chessboard areas; with hybrid street patterns, space samples of traditional and new urban development zones are distributed closer to the peak of the complexity measure values in the triangle. The hybrid topological space samples demonstrate relatively strong irregularity, and also present complex, vivid and flexible street types in different path depths, reflecting relatively strong network heterogeneity.

Taken together, in the spatial syntactic scatter diagram and path structure analysis diagram, the space samples of the urban fringe and suburban settlement zones show similar topological structure characteristics: relatively low integration, intelligence and complexity, and relatively strong recursiveness, and demonstrate relatively concentrated distribution status. At the same time, the measure characteristic values of other types of space samples are relatively discrete, but different types of space samples also present a certain level of differences. Most of space samples with chessboard layout have relatively high integration and intelligence as well as relatively low path structure complexity. The street topological structure of the new urban development zones not only has good traffic accessibility and connectivity, but most of it also has regularized and recognizable path structural patterns. Hybrid topological space samples generally have relatively high spatial integration and intelligence, and present relatively significant complexity in terms of path structural heterogeneity.

V. Conclusion

This paper applies the comprehensive analysis method of street spatial networks to nine local street space samples of five types in a real urban environment, comparatively analyzing the topological and network structural characteristics presented by different types of space samples. Considering the complexity and diversity of street spatial patterns in real cities, compared with traditional spatial quantitative research methods, the comprehensive analysis method of street spatial networks is no longer limited to describing the space network characteristics in a larger range by fragmenting specific street scenes. Instead, starting from the street spatial network structure, it identifies and quantitatively analyzes the spatial pattern subjects of the street network more intuitively and precisely, thus providing feasible quantitative analysis tools for city planners and relevant researchers.

Via the empirical study on different types of real urban local area samples, this chapter verifies the recognition ability of street space network comprehensive analysis method to different spatial geometric forms and network structures, and reveals lots of similarities and differences in the spatial patterns which are hard to identify via intuitive cognition. The samples of the urban fringe and suburban areas present some common topological structure characteristics in the syntactic scatter diagram and path structure analysis diagram: relatively low integration, intelligence and complexity and relatively strong recursiveness, and present relatively concentrated distribution status in the path structure diagram. In contrast, the measure characteristic values of the samples of historical core and urban development zones are relatively discrete, but different types of space samples still present some differences: most space samples with chessboard layout have relatively high integration and intelligence as well as relatively low path structural complexity; The street topological structure of the new urban development zones not only has good traffic accessibility and connectivity, but most of it also has regularized and recognizable path structural patterns; space samples with hybrid topological structures generally have relatively high spatial integration and intelligence, and present relatively strong complexity in terms of path structural heterogeneity. The attractiveness of space samples with hybrid topological structure to individual walking and gathering activities lies between that of chessboard space samples and space samples of new urban development zones.

The vertical and horizontal comparison of space samples with different street patterns, functional positioning and geographic conditions can reveal limiting factors of the space samples in real contextual backgrounds, and how various planning strategies will impact the topological forms of network structures of these space samples. Through diversified space research samples, this paper has completed the empirical quantitative research on the geometric forms of network structures of the street space samples, so as to verify the feasibility, effectiveness and universality of the street space network comprehensive analysis method to different types of urban areas in in a real environment, thus providing helpful space optimization strategies for urban planning and decision analysis, and eventually leading to feasible planning and design outcomes.

ACKNOWLEDGMENT

Thanks are due to Professor Hui Sun for his instructive advice and useful suggestions on the thesis and to Professor Jun Cai for valuable discussion. In addition, the authors wish to thank China Postdoctoral Science Foundation and the Fundamental Research Funds for the Central Universities. This work was supported in part by their support.

REFERENCES

[1] J. Jane, *The Death and Life of Great American Cities*, Random House Press, 1961, pp. 50-52.
[2] C. Alexander, "A city is not a tree: Architectural forum," *Journal of Urban Design*, vol. 122, pp. 58-62, 1965.
[3] C. Alexander, *The Nature of Order*, Oxford University Press, 2000, pp. 90-98.
[4] N. A. Salingaros, *Principles of Urban Structure*, The Techne Press, 2005, ch. 4, pp. 63-65.
[5] C. Alexander, *Notes on the Synthesis of Form*, Harvard University Press, 1964, 78-79.
[6] S, Emanuele, N, Vincenzo, and L, Vito, "Elementary processes governing the evolution of road networks," *Scientific Reports*, vol. 2, pp. 296, 2012.
[7] D. J. Watts, "Collective dynamics of ―Small-world networks," *Nature*, vol. 3, pp. 440-442, 1998.
[8] W. Weaver, "Science and complexity," *American Scientist*, vol. 36, pp. 536-544, 1948.
[9] B. Hiller, "Cities as movement systems," *Urban Design International*, pp. 53-55, 1996.
[10] S. N. Dorogvtsev and J. F. Mendes, "Evolution of networks," *Advances in Physics*, vol. 51, pp. 1079-1187, 2002.
[11] N. A. Salingaros, "Theory of the urban web," *Journal of Urban Design*, vol. 3, pp. 37-41, 1998.
[12] J. Almerima, *Characterization of Complex Networks Application to Robustness Analysis*, Delft University of Technology Press, 2008, ch. 3, pp. 130-132.
[13] B. Jiang and X. Yao, "Geospatial analysis and modelling of urban structure and dynamics," *Geojournal Library*, p. 89, 2010.
[14] B. Hillier, *Space is the Machine: A Configurational Theory of Architecture*, Cambridge University Press, 1999, p. 39.
[15] S. Marshall, *Streets and Patterns*, Routledge Press, 2005, pp. 47-49.
[16] M. Mehaffy, S. Porta, and Y. Rofè, "Urban nuclei and the geometry of streets: The 'emergent neighborhoods' model," *Urban Design International*, vol. 15, pp. 22-46, 2010.
[17] M. Batty and P. Longley, *Fractal Cities: A Geometry of Form and Function*, Academic Press, 1994, pp. 34-39.

Yan Xiao is a lecture at School of Architecture and Fine Art, Dalian University of Technology, Dalian, China. She received her bachelor of urban planning from Dalian University of Technology, China in 2009, she received her MSc degree from University of Technology, China in 2012 and PhD in architectural design and theory at Dalian University of Technology, China in 2015.

Daye Wu is an undergraduate student for a Bachelor's degree on Urban Planning at School of Architecture and Fine Art, Dalian University of Technology, Dalian, China. He graduated from Yangzhong Senior High School of Jiangsu Province, China in 2017.

Zehui Li is an undergraduate student on Urban Planning at School of Architecture and Fine Art, Dalian University of Technology, Dalian, China. She graduated from Tangshan NO.1 Senior High School, China in 2017.

Bingxin Wang is currently studying at the School of Architecture and Art, Dalian University of Technology, China, and is undertaking minor courses in business administration. He is a graduate student for a high school degree in Shuangling Senior High School, Tianjin.