A GRAPH THEORY INTO STREET NETWORK CHARACTERISTICS OF THE PLAIN-TYPE AND THE SLOPE-TYPE HISTORICAL BLOCKS: BASED ON CHINA'S SOUTHWESTERN REGIONS

ZHOU Ding, Master Degree Candidate of Urban Planning, Chongqing University, China

TANG Jichun, Master Degree Candidate of Urban Planning, Chongqing University, China

TAN Wenyong, Associate Professor of Urban Planning, Chongqing University, China

ABSTRACT

Due to the mountainous topography, China's southwestern regions have similarities and differences of street networks in the two-kind historical blocks of plain type and slope type. Sampling 10 typical blocks and basing on the circularity, reachability and circuitousness of graph theory, the paper makes a comparative and quantitative analysis of the street network of these 10 historical blocks from six parameters and their derived parameter indexes: the number of links, the number of nodes, the number of component, the number of intersections, the area of blocks and the length of streets. Research findings demonstrate that when the area of the blocks was similar, there is a significant difference between the number of intersections, the number of components and the length of streets; while that between the rest of parameters is not significant. Combining natural and social factors of their development, we propose the street network-oriented protection and development strategies of historical blocks.

Keywords: graph theory, China's southwestern, historical blocks, street pattern

INTRODUCTION

Many towns in mountainous areas of Southwest China have grown slowly from bottom to top under specific environment, with a long history, and exist in the form of historical blocks in the material level. Due to the topography, there are two types of historical blocks in Southwest China: Plain-type and Slope-type. With the advancement of urbanization, the shape of historical blocks in Southwest China has changed to some extent, but most of them still use the road network which combines the main pedestrian oriented traffic streets with the winding narrow living lanes as the spatial framework. The road network traffic capacity of Plain-type and Slope-type historical block are different, and the complementary mode of streets is also different. However, it constructs a road network form that not only conforms to the local lifestyle, but also maintains the uniqueness of the region.

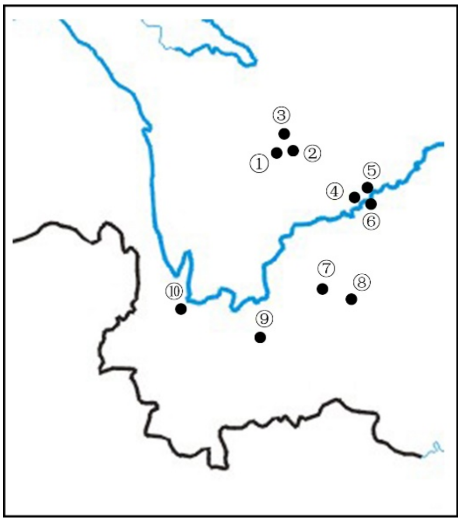
Since the concept of "Historical Blocks" was first formally proposed by the government in 1986, there has been a movement of protection and redevelopment for historical blocks in China. However, the local government has insufficient understanding of the spatial form of historical blocks in the planning. Many traditional streets are regarded as unfavorable factors hindering traffic, so they are modified. As a result, the road network of some original unique historical blocks has changed and some historical environments have been damaged. In the process of practice, in addition to understanding the importance of historical blocks from the perspective of landscape and culture, we must also objectively interpret the spatial morphological characteristics of Plain-type and slope-type historical blocks, so as to avoid the conflict between the development of historical blocks and the protection of historical environment.

THE DEFICIENCY OF PAST RESEARCH AND NEW METHODS

So far, many scholars in Southwest China have studied the road spatial characteristics of the historical blocks in this area. Li Heping analyzed from the geographical point of view, classified the historical built-up environment according to the formation conditions, and determined the relationship between the spatial characteristics of the blocks in Southwest China and the surrounding historical built-up environment as well as the mountain natural environment. Shi Yaling analyzed from the social point of view, through the use of social network analysis method to establish the social network topological structure of historical blocks, and discussed the influence of different street network structure characteristics on the social relations of residents in Southwest China. Xiao Jing analyzed from the perspective of landscape, based on the shape and meaning correlation and dynamic evolution of historical towns, analyzed the spatial form, spatial scale and style characteristics of street space in Southwest China, and concluded that street space is the landscape carrier of historical and cultural image organization and expression.

The results show that the road space of historical blocks plays an important role in the formation of local communities and the maintenance of urban characteristics. However, the past studies basically describe the physical characteristics of the road space of historical blocks from the perspective of single dimension. Some studies tend to focus on the accessibility of main streets, ignoring the study of the overall road network structure. Or it is based on the traditional analysis method of historical plan to review and reflect on the reconstruction and renovation of some winding old streets, but to a certain extent, the relationship between such living lanes and traffic streets is ignored. Therefore, the study of road network characteristics needs to start from a multi-dimensional perspective, based on quantitative basis, to grasp its deep-seated laws.

By introducing mathematical language such as graph theory into the field of space research to assist traditional analysis, we can more accurately reveal the complex physical space morphological characteristics. As a historical carrier and block skeleton, the structure and characteristics of road space have been paid attention to in the current research on the physical space morphological characteristics of historical blocks. We can analyze the spatial characteristics of road network of historical blocks with different formation backgrounds from three aspects, namely, circularity, accessibility and circuitousness This analysis is helpful to quantitatively study the spatial characteristics of the road network in historical districts. Taking the research on the characteristics of historical blocks as the goal orientation, select the corresponding basic information parameters to describe (Fig. 1).



Number	Block	Region	Type	Features	Area
①	Kuanzhai Alley	Chengdu, Sichuan	Plain-type	Neighborhood	7.8ha
②	Wenshufang Block	Chengdu, Sichuan	Plain-type	Religious District	7.0ha
③	West Street	Dujiangyan, Sichuan	Slope-type	Business District	3.7ha
④	Ciqikou Block	Shapingba, Chongqing	Slope-type	River Port	6.7ha
⑤	Cuntan Block	Jiangbei, Chongqing	Slope-type	River Port	5.3ha
⑥	Fengsheng Ancient Street	Banan, Chongqing	Slope-type	Business District	7.1ha
⑦	Guanyipo Block	Panzhou, Guizhou	Plain-type	Neighborhood	8.6ha
⑧	Jiuzhou Ancient Street	Anshun, Guizhou	Slope-type	Military Pass	2.8ha
⑨	Wenming Street	Kunming, Yunnan	Plain-type	Business District	7.1ha
⑩	Shuigetan Block	Dali, Yunan	Plain-type	Business District	3.1ha

Figure 1. Basic information of selected block sample

RESEARCH METHODS BASED ON GRAPH THEORY

"Graph theory" is one of the important theoretical bases to explore the system structure. In spatial research, the basic spatial elements of buildings or blocks are regarded as "nodes", and the channels connecting these elements are regarded as "edges". Nodes and edges form a spatial topological structure. This structure, called graph, is a mathematical model to express the relationship between things in an abstract way. The focus of graph theory is to explore the connection between nodes without considering their shape, size, distance and direction. Graph theory focuses on the analysis of spatial accessibility, spatial network pattern characteristics, the relationship between spatial structure and social activities, and has a strong spatial analysis ability. The traditional qualitative inductive analysis method will fall into the endless spatial form summary, so the spatial organization structure abstracted by topological relations is a more optimized spatial research object.

According to the general method of graph theory and considering the different actual road network shape of each research object, three rules are set up to divide the road network for each sample. First of all, the scope of the historical block determined by the government is based on the clearly marked boundaries in the urban planning. However, due to the existence of mountains and farmland, the boundaries of traditional towns are very wide. In order to compare on a similar scale, the main residential areas of towns with relatively dense roads are selected as the scope area of road network. Secondly, different types of roads in the road network have different influences on the overall block shape characteristics. In order to clarify the relationship between road morphology and spatial characteristics, the overall road network structure is divided into Traffic Street with street width greater than 4m and living roadway with street width less than 4m. Furthermore, the plane form of road can be divided into straight line, zigzag line and curve. If the two ends of the road can be connected by a straight line within the width of the road, it can be considered that the road with lower curvature has a straight form.

Based on graph theory, this study defines the circularity, accessibility and circuitousness of road network, and lists the geometric characteristic indexes that can be used to quantitatively describe the above three properties in the selected historical block samples, which are the number of streets, the number of nodes, the number of units, the number of intersections, the area of blocks, the length of streets and their derived parameters (Fig. 2).

Attribute	Parameter	Formula	Explain
Circularity	Number of circular roads: μ	$\mu = e - v + p$	e: number of edges; v: number of nodes; p: number of units
	Average number of circular roads: μ_a(n/ha)	$\mu_a = \mu / S$	S: area of block
	α factor(%)	$\alpha = \mu / (2v - 5)$	In a fully connected network, the number of circular roads $\mu_c = (2v - 5)$
	β factor	$\beta = e / v$	Average number of passes per node
	γ factor(%)	$\gamma = e / 3(v - 2)$	In a fully connected network, the number of edges $e_c = 3(v - 2)$
Accessibility	Average accessibility: Ai	$Ai = \frac{\sum_{j=1}^{n} d(i,j)}{(n-1)}$	i: the average minimum distance between all nodes; d(i,j): Minimum distance between nodes
	Average dispersion: Di	$A = \sum_{i=1}^{v}\sum_{j=1}^{v}\frac{d}{dl}(i,j) / v(v-1)$	Excluding the influence of node number from the sum of average accessibility
	Density of roads: Dl(m/ha)	$Dl = L / S$	L: total length of road; S: area of block
	Density of nodes: Dc(n/ha)	$Dc = v_c / S$	v_c: number of road intersections; S: area of block
Circuitousness	Radio of detour A'	$A' = \frac{\sum_{j=1}^{n}\frac{d}{dl}(i,j)}{(n-1)}$	i: the average ratio of the minimum distance between all nodes and the straight line distance; d(i,j): the ratio of the minimum distance between nodes to the straight line distance
	Average radio of detour A	$Di = \sum_{i=1}^{v}\sum_{j=1}^{v} d(i,j) / v(v-1)$	Average ratio of minimum distance to straight line distance between road networks

Figure 2. Road network analysis index

First of all, the circulation of road network refers to the degree of repetition of people wandering aimlessly in the road network. From a geometric point of view, the index depends on the number of ring roads in the network and the number of nodes and edges that make up the ring road. Therefore, the circularity can be evaluated by three indicators □, □ and □. If any specified edges in the network are removed to prevent the formation of a complete graph, the graph is considered as a "tree-graph". If each node in the graph can form edges with each other, the graph is considered as a "complete connection-graph". The type of graph can be determined according to the mathematical relationship between nodes and edges. In this study, □ index represents the number of ring roads in the network, and □ index is the ratio of the number of ring roads to the actual number of ring roads when the nodes in the graph can form edges with each other. The □ index represents the ratio of the number of nodes to the number of edges in the graph, which represents the average number of corresponding edges to each node. The □ index is the ratio of the number of edges required to connect all nodes in a graph to the number of actual paths. These indicators complement each other and reflect the cycle degree of road network. The higher the value, the better the relative road network circularity (Fig. 3).

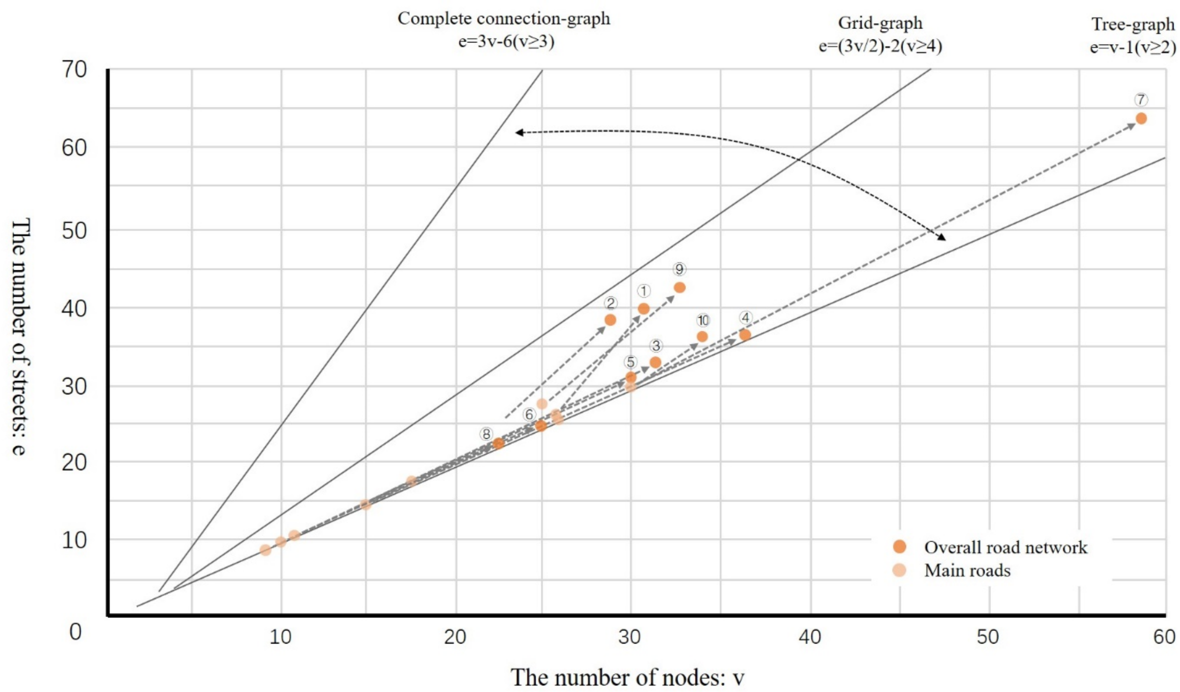


Fig. 3 The relationship of road network morphology in the study area

Secondly, Ai is the average of the minimum distance from any given node to any other node in the graph, which is used to evaluate the accessibility of the specified node. Di is the average value of Ai value of all nodes, which is used to evaluate the accessibility of the whole road network. The smaller the di value is, the shorter the relative distance required for people walking in the road network to reach each node, the better the accessibility of the whole road network. Some studies show that the range and density of nodes and edges are directly related to di index. In this study, the road network density Dl and node density Dc are used to evaluate the road network accessibility.

Finally, detour is defined as the ratio of the actual distance from one node to any other node to the linear distance between two nodes in the graph. The detour rate A' is used to indicate the degree of detour in the entire road network. The higher the bypass rate is, the more circuitous the road network is, that is, the more circuitous a person must take to reach the designated node.

According to the following three standards, 10 historical blocks with good road network retention are selected as the research objects, and the characteristic data of each block are noted (Fig. 4). First of all, considering the influence of historical background on the form of road network, the selection range of blocks ranges from villages relying on agriculture, forestry and fishery to cultural blocks relying on commerce or religious temples. Secondly, considering the influence of geographical conditions, the selection objects include relatively independent areas between mountain areas and historical blocks located or close to the city. In addition, in order to reduce the impact of modern roads on the form of historical road network, the following more appropriate research objects are selected: first, according to the local historical records, the original road network is well preserved and continues to be used; second, the area close to the city but less affected by Urbanization, most of the block shape is well preserved; third, it belongs to the historical and cultural protection area and the original A city block with historical road form.

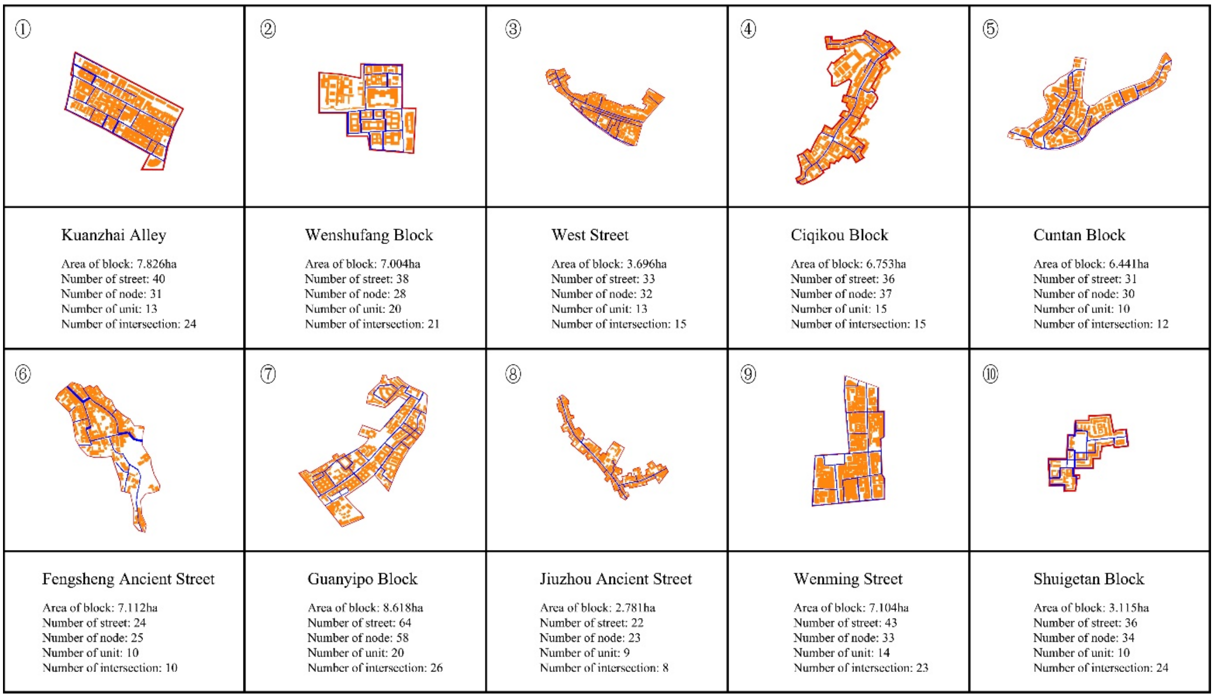


Figure 4. Block feature information of the research object

RESEARCH PROCESS

Through calculation, the road network data analysis results of 10 historical blocks are obtained (Fig. 5). First of all, in terms of the number of ring roads, the overall road network □ value of Wenshufang Block, Guanyipo Block and Wenming Street exceeds 15, which is higher than that in other areas. In contrast, the overall road network □ value of West Street, Ciqikou Block, Cuntan Block, Fengsheng Ancient Street, Jiuzhou Ancient Street and Shuigetan Block is less than 15. In terms of the average number of circular roads, the □$_a$ value per unit area of West Street, Jiuzhou Ancient Street and Shuigetan Block has been significantly increased, but the analysis results of other blocks are basically consistent with the trend of the overall road network □ value (Fig. 6). Through comprehensive analysis, it can be found that there are more ring roads formed in plain-type historical block than in slope-type historical block, and the circulation is higher on the whole. But there are still three blocks that have the opposite result locally. This finding shows that the local circulation of the slope-type historical block is good, but the overall circulation of the block is still not strong because of the uneven distribution of road network density due to the influence of terrain.

Number	Name	the length of streets			Overall road network														Block	
		Total	Main roads	Lanes	e	v	Terminal node	Intersection	μ	μa	α	β	γ	Di	Dl	Dc	A		Area	Unit
1	Kuanzhai Alley	2386	1177	1209	40	31	4	24	22	2.811	0.386	1.290	0.460	77.048	304.873	3.067	1.189		7.826	13
2	Wenshufang Block	1976	1321	655	38	28	1	21	30	4.283	0.588	1.357	0.487	69.333	282.116	2.998	1.077		7.004	20
3	West Street	1400	962	438	33	32	17	15	14	3.788	0.237	1.031	0.367	90.505	378.798	4.059	3.673		3.696	13
4	Ciqikou Block	1498	826	672	36	37	18	15	14	2.073	0.203	0.973	0.343	102.641	221.844	2.221	2.313		6.753	15
5	Cuntan Block	1895	984	911	31	30	10	12	11	1.708	0.200	1.033	0.369	152.823	294.232	1.863	3.025		6.441	10
6	Fengsheng Ancient Street	1483	1086	397	24	25	11	10	9	1.265	0.200	0.960	0.348	154.479	208.518	1.406	2.181		7.112	10
7	Guanyipo Block	2517	1140	1377	64	58	14	26	26	3.017	0.234	1.103	0.381	87.732	292.067	3.017	1.561		8.618	20
8	Jiuzhou Ancient Street	776	619	157	22	23	10	8	8	2.877	0.195	0.957	0.349	101.409	279.046	2.877	3.008		2.781	9
9	Wenming Street	2665	1620	1045	43	33	4	23	24	3.378	0.393	1.303	0.462	88.923	375.120	3.237	1.329		7.104	14
10	Shuigetan Block	1498	962	536	36	34	7	14	12	3.852	0.190	1.059	0.375	101.056	480.853	4.494	1.443		3.115	10
Number	Name	the length of streets			Main roads														Block	
		Total	Main roads	Lanes	e	v	Terminal node	Intersection	μ	μa	α	β	γ	Di	Dl	Dc	A		Area	Unit
1	Kuanzhai Alley	2386	1177	1209	26	26	2	22	13	1.661	0.277	1.000	0.361	88.868	150.392	2.811	1.692		7.826	13
2	Wenshufang Block	1976	1321	655	25	23	3	17	22	3.141	0.537	1.087	0.397	130.965	188.601	2.427	1.205		7.004	20
3	West Street	1400	962	438	8	9	2	7	12	3.247	0.923	0.889	0.381	446.209	260.288	1.894	1.506		3.696	13
4	Ciqikou Block	1498	826	672	14	15	3	12	14	2.073	0.560	0.933	0.359	142.713	122.325	1.777	1.417		6.753	15
5	Cuntan Block	1895	984	911	9	10	2	8	9	1.397	0.600	0.900	0.375	286.468	152.783	1.242	1.489		6.441	10
6	Fengsheng Ancient Street	1483	1086	397	17	17	4	8	10	1.406	0.345	1.000	0.378	190.872	152.698	1.125	1.595		7.112	10
7	Guanyipo Block	2517	1140	1377	29	30	8	19	19	2.205	0.345	0.967	0.345	132.283	132.283	2.205	1.345		8.618	20
8	Jiuzhou Ancient Street	776	619	157	10	11	3	8	8	2.877	0.471	0.909	0.370	222.590	222.590	2.877	1.471		2.781	9
9	Wenming Street	2665	1620	1045	27	25	4	17	16	2.252	0.356	1.080	0.391	198.717	228.028	2.393	1.418		7.104	14
10	Shuigetan Block	1498	962	536	25	26	6	14	9	2.889	0.191	0.962	0.347	190.878	308.799	4.494	1.195		3.115	10

Figure 5. Road network data analysis results

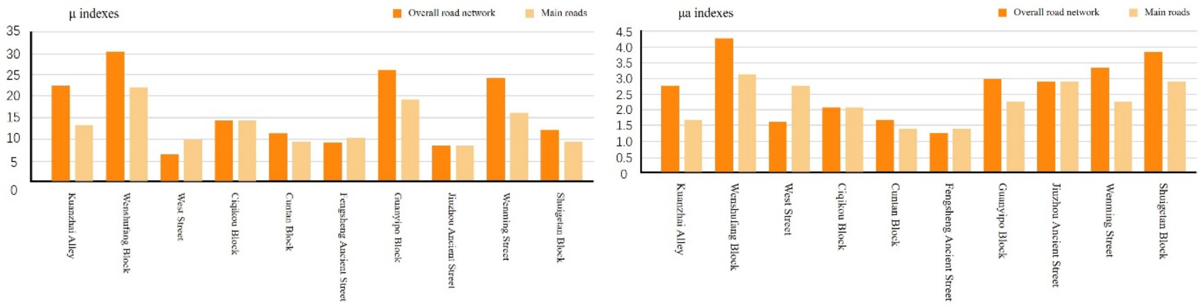


Figure 6. Number of circular roads (μ) and average number of circular roads (μa)

Secondly, the index value of the overall road network of the plain-type historical block is higher than that of the slope-type historical block. On the contrary, when only the main roads are analyzed, the index value of the slope-type historical block is higher than that of the plain plain-type historical block (Fig. 7). On the whole, the road network form of plain-type historical block is closer to the " complete connection-graph ", that is, when people move in a circular way, the traffic efficiency is higher. By comparing the index of the overall road network and the main roads, we can find that the change degree of the plain-type historical block is small, which indicates that the connection degree between the traffic streets and the living lanes is high, and the overall connectivity is good. The results show that the living lanes in the slope-type historical block are basically "blind alley" due to the complex terrain, and the connectivity is poor.

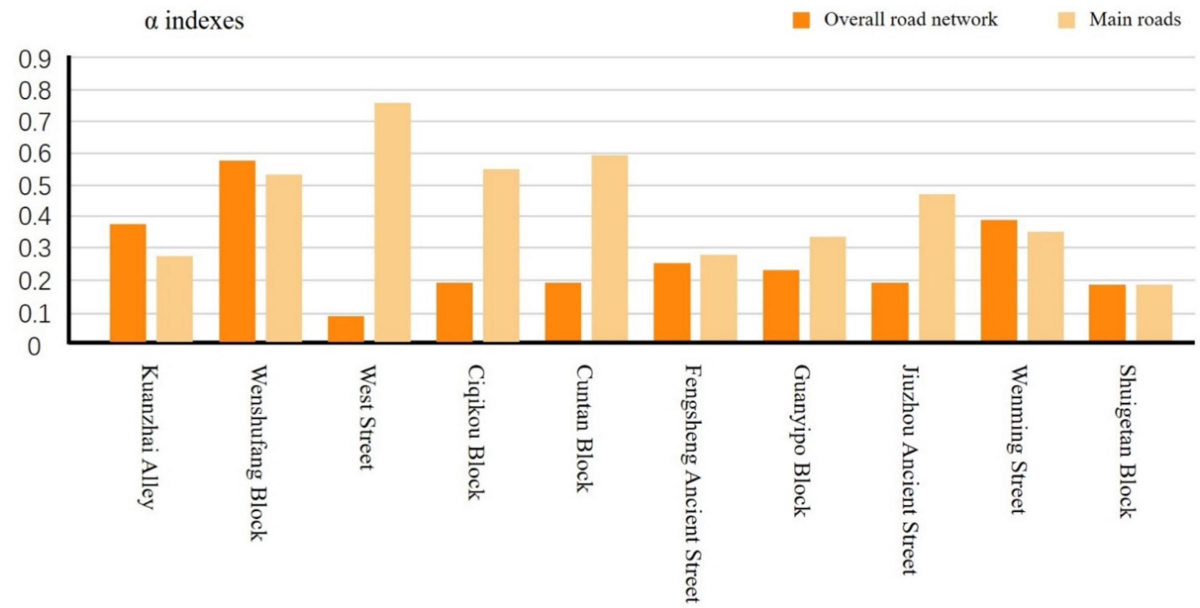


Figure 7. index

Finally, the road network of each historical block is evaluated according to and indexes (Fig. 8). When the road network is close to the " complete connection-graph", the values of and increase with the increase of the number of streets. Therefore, the number of nodes and streets needed to form a ring road network can be determined by using and indexes when there is no cross road detected and the road network shape is similar in the region. These indicators reflect the circulation of road network to a certain extent. The higher the value, the less nodes and connections needed to form the ring road network. Through the analysis, it can be found that the index value of plain-type historical block is more than 1.0, among which the and index values of Kuanzhai Alley, Wenshufang Block and Wenming Street are close to 1.4 and 0.5 respectively, which indicates that the plain-type historical block has better circulation than the slope-type historical block.

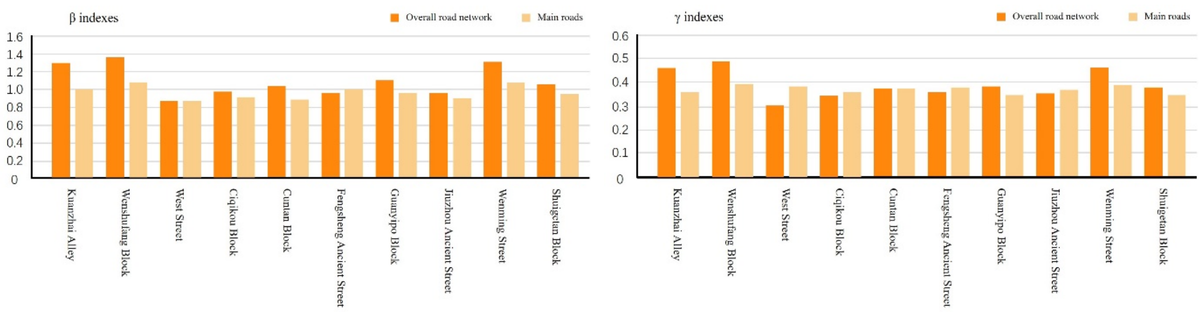


Figure 8. index and index

The accessibility of road network is analyzed based on road density Dl, node density Dc and average discrete Di. Firstly, the road density Dl and node density Dc in each historical block are compared and analyzed. On the whole, the dl and Dc values of plain-type historical block are more than 300 and 3 respectively, which is higher than that of slope-type historical block. The results show that the road network of plain-type historical blocks is relatively dense. Secondly, the di value of slope-type historical block is higher than that of plain-type historical block (Fig. 9). The areas with the highest average discrete Di of main roads are West Street and Cuntan Block. The results show that the average distance between the two nodes is relatively large, so the overall accessibility is relatively poor. When the shape and density of the road network in such areas are combined, the relationship between the two nodes is monotonous, and the traffic streets are sparse and " tree-graph ". In contrast, the analysis results of the whole road network of historical blocks show that the di value of most of the road network of historical blocks has decreased, which shows that the narrow living roadway shortens the distance between two nodes in the regional road network, and plays a certain role in enhancing the accessibility of historical blocks.

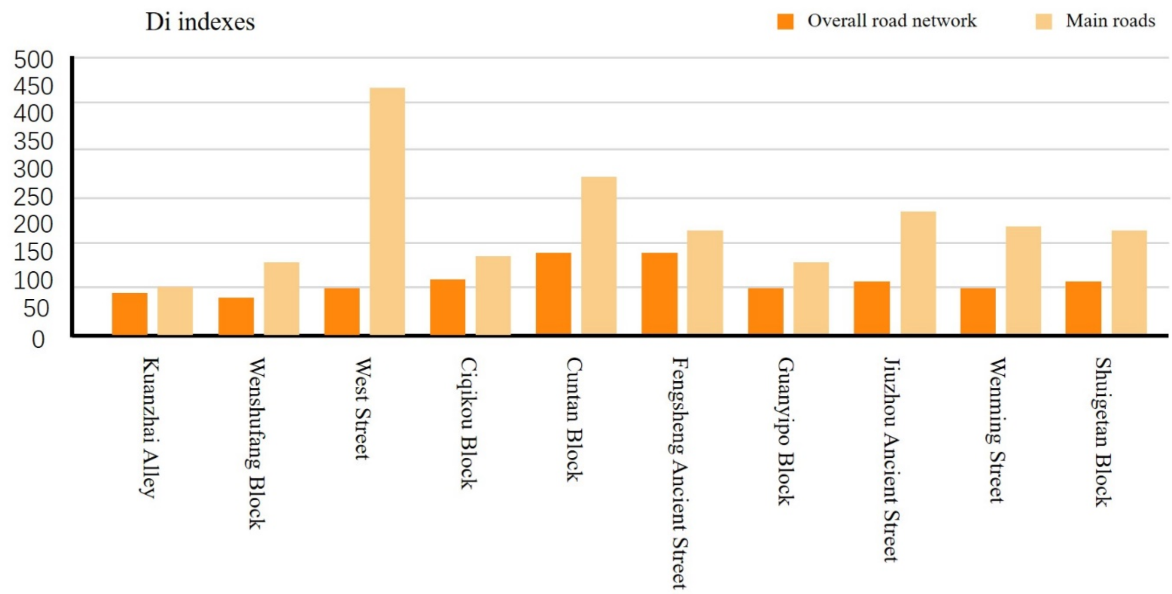


Figure 9. Average dispersion index (Di)

The average radio of detour A values of slope-type historical blocks are all above 2.0, among which the A value of West Street is 3.67, and the A value of Cuntan Block and Jiuzhou Ancient Street are both more than 3.0 (Fig. 10). It can be seen that the connection between the nodes in the slope-type historical block is weak as a whole, and pedestrians in this area must walk more than three times the average straight-line distance to reach the destination. Therefore, the slope-type historical block has strong circuitousness and poor traffic convenience. Through the analysis of the average A value of the main roads, the A value is reduced in different degrees. It can be seen that the life roadway of slope-type historical block enhances the detour of this kind of area due to the influence of complex terrain. The A value of plain-type historical block changes little, because the road network shape of this kind of area is close to " complete connection-graph " or " grid-graph ", and the traffic street and living lanes are basically connected with each other, so the A value of most blocks is below 1.5, and the roundabout is relatively low.

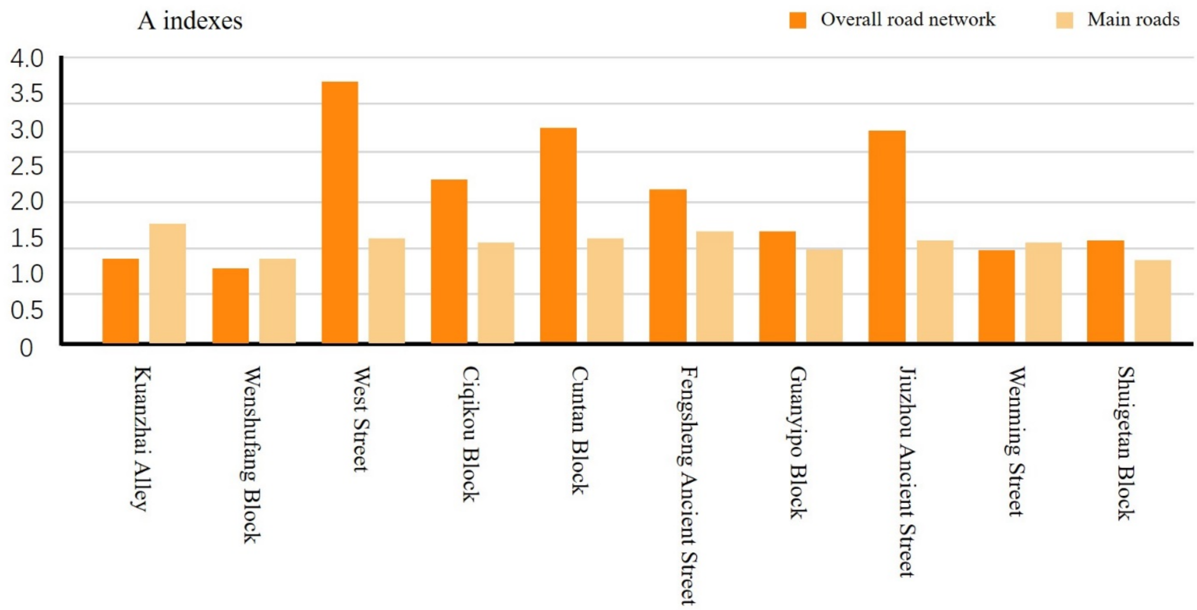


Figure 10. Average bypass ratio (A)

According to the general method of graph theory, the circulation, accessibility and circuitousness of each research object road network are analyzed quantitatively. Through quantitative analysis of the six main parameters of the overall road network of each historical block, including the number of streets, the number of nodes, the number of units, the number of intersections, the area of blocks and the length of streets, it is found that when the area of blocks is similar, there are significant differences in the number of intersections, the number of units and the length of streets, while other parameters are not significantly different (Fig. 11).

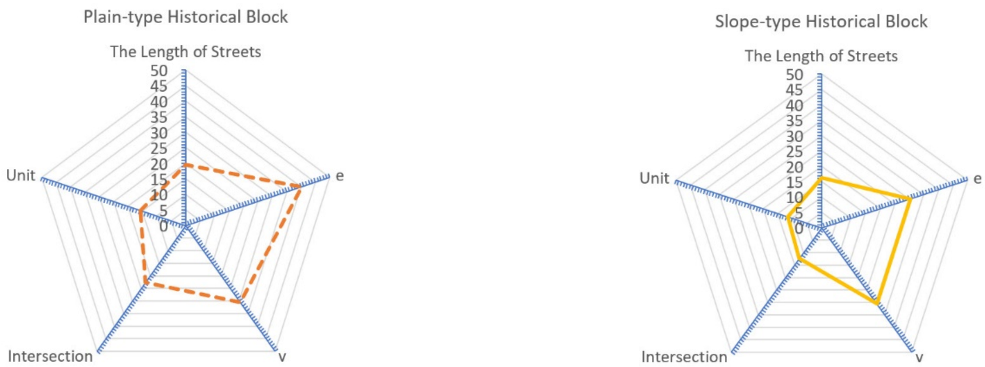


Figure 11. Difference of main parameters between two types of historical blocks

In order to fully understand the spatial form and structure reflected by the above characteristics, the values of 11 indicators (e, v, □, □$_a$, □, □, □, Di, Dl, Dc and A) of the overall road network and main roads were taken as variables. According to the differences of road network morphological characteristics of different historical blocks, the standardized comparative analysis was carried out between the plain-type historical block and the slope-type historical block. The distribution of the mean can clearly identify and describe the two types of features in detail (Fig. 12).

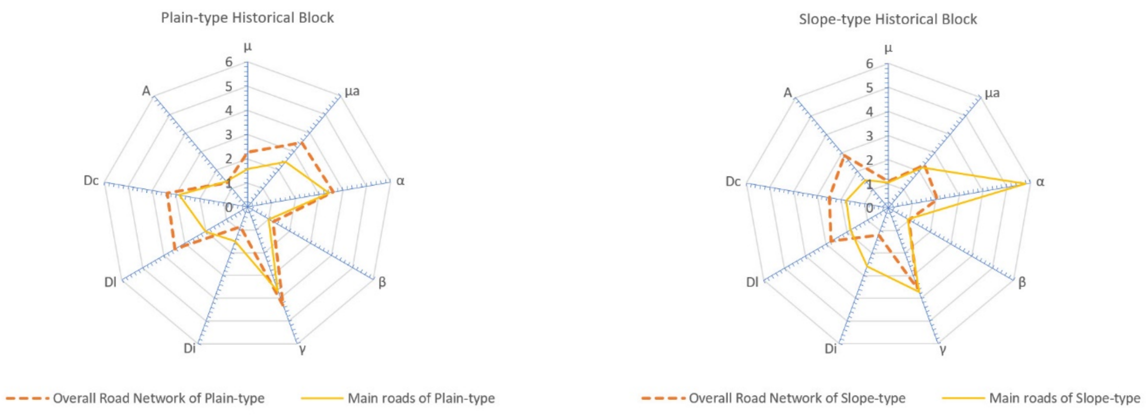


Figure 12. Spatial characteristics of two types of historical blocks

Most of the plain-type historical blocks are located in the city, developed from residential blocks, commercial blocks or religious blocks. The main roads and the overall road network structure are close to the " grid-graph", with high circularity and accessibility index values, and low circuitousness index values. There is no obvious difference between the three index values of the main road and the whole road network structure, which indicates that in the plain historical blocks The main reason is that the stable road network structure is composed of traffic streets, while the living lanes only slightly affects the formation of the whole road network.

Most of the slope-type historical blocks are located in the urban fringe or mountainous area, developed from the port, commercial block or military pass. There are few ring roads in the main roads and the overall road network structure, and most of them are "tree-graph". Compared with the plain-type historical blocks, they have lower circularity and accessibility index values, and higher circuitousness index values. The terrain environment has a profound impact on the slope-type historical blocks, and the index values between the main roads and the overall road network structure show significant changes. When only considering the traffic streets, the circularity index has improved to a certain extent, but the accessibility index has changed in different degrees, which shows that the traffic street and the living lanes form a good complementary relationship in this kind of area. Without any of them, the whole road network structure will be greatly damaged.

CONCLUSION AND SUGGESTION

The historical blocks in the mountainous area of Southwest China have different road network structure characteristics due to the factors of topography and landform. Based on the circularity, accessibility and circuitousness of graph theory, this paper analyzes two types of historical blocks: plain-type and slope-type, and draws the following conclusions.

First, when the street area is similar, there are significant differences in the number of intersections, the number of units and the length of streets between the plain-type and the slope-type historical block. The three indicators of the plain-type historical block are higher than that of the slope-type historical block, and the other parameters are not obvious.

Secondly, the main roads and the overall road network structure of the plain-type historical block are close to the "grid-graph", with high circularity and accessibility index value, and low circuitousness index value. Its traffic streets constitute a stable road network structure, while the living lanes only weakly affects the formation of the whole road network.

Thirdly, there are few ring roads in the main roads and the overall road network structure of slope-type historical blocks, which are mostly "tree-graph ", with low circularity and accessibility index value, and high circuitousness index value. The traffic streets and living lanes form a good complementary relationship, and the lack of any of them will greatly damage the overall road network structure.

The protection and development strategies of the two historical blocks should be based on the common and individual characteristics of their road network, combined with the natural and social factors of the road network development of historical blocks. In terms of spatial form, plain-type historical blocks are more "two-dimensional" plane extension, streets and alleys are changing on the plane, while slope-type historical blocks have a "three-dimensional" sense of hierarchy. Due to the ups and downs of the mountain terrain, the streets and alleys turn and bend in the vertical direction, forming a road network spatial form different from the plain-type historical blocks.

Therefore, for the plain-type historical block, we should focus on protecting the traffic street, improving the connection between the traffic street and the living lanes, maintaining the advantages of circulation and accessibility, and further reducing the detour. For slope-type historical blocks, traffic streets and living roadways are equally important. Efforts should be made to avoid the reduction of living alleys caused by development and construction, and to avoid the circularity and accessibility of the overall road network structure from being greatly damaged. It is necessary to dredge and optimize the connectivity between living alleys and traffic streets as far as possible, so as to improve the circuitousness of such areas.

REFERENCES

Fei Chen. (2012). Interpreting urban micromorphology in China: case studies from Suzhou. Urban Morphology,16(2):133-148

(1986). Report of the Ministry of Urban and Rural Construction and Environmental Protection and Ministry of Culture on the announcement of the second batch of national famous historical and cultural cities. The Bulletin of the State Council of the People's Republic of China, (35):1075-1086.

Ruan Yisan, and Sun Meng. (2001). The study on some issues related to the conservation and planning for the historic streets and areas in China. City Planning Review,25(10),25-32.

Li Heping. (2004). The study on the conservation of historic built environment Chongqing. Chongqing University.

Shi Yaling, and Huang Yong. (2018). A study on the relevance between physical form and social network of historical district. Planners,34(8),101-105.

Xiao Jing. (2015). Evolution process and dynamic mechanism analysis of historic town cultural landscapes in Southwest Mountainous Area. Chongqing University.

Jin Lichun, and Jiao Sheng. (2019). A Graph Theory Based Study on the Structure of Public Space in Traditional Villages. Planners,35(2),52-57.

Kong Yawei, Zhang Jianhua, Yan Ruihong, and Han Xue. (2016). Multi-layered evidences in the analysis of the cause for spatial formation of traditional settlements a multidisciplinary study on Wangfuchizi Area in Jinan by graph theory, graphics and historical geography. Architectural Journal,0(5),86-91.

Liu Xingming. (2014). Study on the planning of network and facilities of historic district slow traffic system. Xi'an University of Architecture and Technology.

Wang Yuchun .(2019). Analysis and Evaluation on the Internal Accessibility of Pedestrian Historic Blocks. Urbanism and Architecture,16(18),16-25.

Liang Chengcheng. (2017). Traffic microcirculation guidance of mountain (Live) block updating strategy research—taking Chongqing Beibei HeHuachi Distras a case on study. Chongqing University.

Lv Haiping ,Zhang Hecheng, and Liu Zhonggang. (2017). Quantitative analysis on spatial morphological parameters of Zhongshan Road in Shenyang Historic-Culture Areas. Journal of Shenyang Jianzhu University：Social Science,19(5),446-451.

Urban, D., & Keitt, T. (2001). Landscape connectivity: A graph-theoretic perspective. Ecology (Durham), 82(5), 1205-1218.

Wu, B., Yu, B., Wu, Q., Chen, Z., Yao, S., Huang, Y., & Wu, J. (2018). An extended minimum spanning tree method for characterizing local urban patterns. International Journal of Geographical Information Science, 32(3), 450-475.

Zhang Hong, Wang Xinsheng, and Yu Ruilin. (2006). Space syntax and its research progress. Geospatial Information,4(4),37-39.

WATANABE, K., HARA, H., FUJII, A., & YAMANAKA, T. (1983). APPLICATION OF GRAPH THEORY ON ARCHITECTURAL PLANNING : Part 1 basic analysis. Transactions of the Architectural Institute of Japan, 334, 117-127.

TAKAGI, M., TANIGUCHI, H., & KIM, J. (1991). BASIC STUDY OF INDEXES OF GRAPHS AND NETWORKS AND ANALYSIS OF STREET STRUCTURES OF UNDERGROUND TOWNS BY APPLYING THEM : Studies on an analysis method of trafic lines of architectural planing applying indexes and the theory of graphs and networks part 1. Journal of Architecture, Planning and Environmental Engineering (Transactions of AIJ), 422, 37-44.

Graham, R. L., Hoffman, A. J., & Hosoya, H. (1977). On the distance matrix of a directed graph. Journal of Graph Theory, 1(1), 85-88.

Koshizuka, T. (1978). A new method for analyzing road networks. City Plan. Inst. Jpn. 103, 36–41.

Tamura, K., Koshizuka, T., Ohsawa, Y. (2001). Relationship between road distance and euclidean distance on road networks. City planning review. Special issue, Papers on city planning, 36, 877–882

CORRESPONDING AUTHOR

TAN Wenyong, Associate Professor, School of Architecture and Urban Planning, Chongqing University, No.174 Shazhengjie, Shapingba, Chongqing, 400044, China. laotan1968@126.com