Research Paper

Quantitative analysis and development guidance of the spatial morphology of ancient towns in southern Shaanxi

Haizhao HAO, Xi'an University of Architecture and Technology, China
Xiaojian CHEN, State Key Laboratory of Green Building in Western China, Xi'an University of Architecture and Technology, China

Abstract

The ancient town is a small town that has survived in history, and its traditional form is basically unchanged. In recent years, some ancient towns have experienced the destruction of the traditional spatial structure, the disappearance of the sense of place, and the breaking of context in the process of economic development. How to not only inherit the historical context, but also meet the current development demands, and improve the connection between history, the present and the future, has become an urgent problem to be solved in the development process of the ancient town. First of all, this article quantitatively analyzes the spatial form of the ancient town in southern Shaanxi from the aspects of physical boundary, land use, street and building. Secondly, on the basis of quantitative analysis, the paper analyzes the reasons for the differences in indicators between different ancient towns from the aspects of environment, economy, transportation and residents' needs. Finally, the author attempts to search for ways to improve the connectivity of history, present and future in the development of ancient towns, in order to provide references for the development of ancient towns at home and abroad.

Keywords

Ancient town in southern Shaanxi, Spatial form, Quantitative analysis, Development guidance

1. Introduction

The research object of urban morphology has always been closely integrated with the material space of the city, and with the development of science and technology. The methods of urban morphology research are increasingly developing in the direction of quantification and digitization. Different from pure qualitative research methods that lack quantitative descriptive or descriptiveness, quantitative research is based on data and models to make the analysis results relatively objective and accurate. From the perspective of the quantitative research on urban morphology, it is not the research method that has only been formed in recent years. From the early days of urban morphology, the spatial measurement and analysis of buildings and blocks is the most basic quantitative method. For example, the early analysis of German town plans involved the measurement of plot boundaries and dimensions. In the book " The Death and Life of Great American Cities " written by Jane Jacobs in 1961, it is proposed that cities as complex organisms have diversity and need to use a new way of thinking of complex systems to solve the problems of big cities, while qualitative analysis, traditional measurement analysis or econometric methods seem to be unable to effectively solve the complex problems of complex systems. This research has become one of the classical theoretical foundations of quantitative research on urban morphology. In the modern sense, the book that takes the quantitative study of urban morphology as a theoretical method is the book "spatial social logic" written by B. Hillier and J. Hanson in Britain in 1984. This study puts forward the spatial analysis technology of spatial syntax. The quantitative analysis of urban form in China has gradually changed from static structural form analysis to dynamic space-time succession analysis, from interpretation to simulation and prediction, from two-dimensional analysis to three-dimensional visualization. Ai Nanshan (1994), Zhang Yuxing (1995), and Li Jiang (2004) use geographic information systems and remote sensing technologies to study urban spatial morphology. Yang Junyan (2006) uses quantitative methods to study the spatial form of urban central areas. Duan Jin (2007, 2015), Yang Tao (2006), and Sheng Qiang (2014) apply spatial syntax to spatial cognition, architectural design, and urban planning management.

In recent years, with the improvement of urbanization and the rise of ancient town tourism, the space of most historical and cultural villages and towns in China has expanded significantly (Wei fengqun et al., 2016). In the process of spatial expansion, the spatial form of the ancient town has problems of uncoordinated development, such as the uncoordinated style of the old and new areas, the unbalanced land layout, and the chaotic spatial order (Peng Jun, 2010). The international charter and the policies of the Chinese government have gradually increased their emphasis on the coordinated development of new and old regional spaces. In the regulations on the protection of famous historical and cultural cities, towns and villages in 2008, it is proposed that "famous historical and cultural villages and towns should maintain and continue their traditional pattern and historical style, and correctly handle the relationship between economic and social development and the protection of historical and cultural heritage". In 2011, "Proposal on Historic Urban Landscapes" advocated the formation of a continuous and harmonious relationship between the past, present and future of urban space and social relations (Oers R.V, Zhou Jian, 2012). The coordinated development of the spatial form of the new and old areas of the ancient town can meet the needs of the protection of the old area of the ancient town and the development of the new area (Huang Liwei et al., 2018). Coordinated development refers to promoting the development of different system elements from a disordered and differentiated state to an orderly and coordinated state. The synergy between different subsystems can form an overall macroscopic motion form that is better than the sum of the motions of each part (H.Haken, 2005). The spatial development of the ancient town should realize the continuation of history, reality and the future. The old area of the ancient town should protect the traditional spatial characteristics, and the construction of the new area should continue the spatial context.

The scientific measurement of the status quo of the spatial coordination of the new and old regions is the basis of the coordinated development strategy. However, from the quantitative analysis of the existing spatial form, it mainly evaluates the overall protection status, value and urban style of ancient villages and towns. There is a lack of evaluation on the internal differentiation of ancient towns in relevant studies. Therefore, based on previous studies, this study evaluates the differentiation status of the old and new areas of ancient towns in southern Shaanxi, and analyzes the main influencing factors that affect the differentiation status. Finally, the morphological development guidance strategy of ancient towns in southern Shaanxi is proposed to provide reference for the coordinated development of historical and cultural villages and towns.

2. Research area and quantitative analysis method

2.1. Research area

The ancient town of Southern Shaanxi is located in the Qinba Mountains. The traditional buildings, ancient streets, and cultural relics left over to this day are rare living fossils of the traditional culture of Southern Shaanxi. They are typical and representative of China's excellent regional culture. From the perspective of its spatial distribution, the ancient towns of southern Shaanxi are mainly located on important transportation lines that pass through the Qinling Mountains and Bashan Mountains and connect the Guanzhong area with Sichuan and Hubei provinces. Judging from the historical background of the formation of the ancient town, historically busy shipping and commercial activities have greatly promoted the economic development of southern Shaanxi and the exchange and integration of multiple cultures, making the ancient town of southern Shaanxi form a landscape that brings together various architectural styles from the north to the south. In recent years, affected by the improvement of urbanization and the development of tourism, the spatial form of ancient towns in southern Shaanxi has developed disorderly and the layout of buildings has been chaotic. This study selected the representative towns of Qingmuchuan, Manchuanguan, Shuhe, Fenghuang, and Wuguan among the ancient towns in southern Shaanxi for detailed quantitative analysis.

2.2. Data Sources

The data sources in this study mainly come from aerial photographs of drones and data from field surveys. The current boundary of the ancient town is to delimit the main built-up area on the basis of drone aerial photos. The scope of the old area refers to the historical boundary of the Qing Dynasty. The scope of the new area refers to the area outside the old area in the concentrated construction area of ancient towns. The land use data and the number of building floors come from on-site surveys. The data of floor area ratio and building density are calculated based on drone aerial photographs and field survey data.

2.3. Quantitative analysis method

2.3.1. Analysis of Measurement Methods in Related Research

The measurement indicators in related studies are mainly developed from spatial structure, land layout, street and courtyard, and mainly use mathematical analysis, spatial syntax analysis, and GIS analysis.

Spatial structure is the internal connection of functional activities and the projection of socio-economic structure on land use(WU Zhiqiang&LI Dehua,2011). Existing researches have been carried out mainly from the aspects of urban pattern, urban context and urban texture that make up the spatial structure. Zhang Jie & Wu Yanan (2010) quantify the traditional village morphology from the four aspects of site selection, axis, scale and sight. Wang Yansong et al. (2012) selected the indicators of mountain surrounding, openness, average water body width, water body slope, and plant coverage to measure the settlement landscape pattern. Tong Lei (2016) evaluated the rationality of spatial texture using texture similarity index.

The layout of land use is an intuitive expression of the function of the plot in the space. A reasonable layout of the ancient town land can save land resources and promote the coordinated development of the old and new areas. Quantitative research on land layout has been carried out from the aspects of land use efficiency and development intensity. Lin Zhaowu (2015) selected land use scale, land use ratio, building density, floor area ratio and other development intensity indicators to quantitatively analyze the land use form. Wei Lang et al. (2018) selected spatial entropy and dissimilarity index to analyze land use patterns. Ye Yu et al. (2016) selected indicators such as functional mixing degree, construction intensity, and building form to describe the characteristics of urban spatial form.

The street is an important element in the urban form. The related research mainly quantifies the streets from the aspects of geometric relations, aesthetic standards, and traffic efficiency. Yuan Sinan (2012) selected topological indicators and street network density to analyze street networks. Ding Wovo et al. (2013) analyzed the richness of streets by the number of different types of road intersections and their proportion in the total road intersections. There are also many scholars who use spatial syntactic connectivity, topological depth and other indicators to quantitatively analyze street shapes(DUAN Jin,2007; Sun Tongyu et al.,2019).

The building is the basic unit of urban space and the bottommost element of the organizer of urban space. Relevant research mainly selects indicators from the courtyard's geometric relationship, combination relationship, position relationship for quantitative analysis. He Yi et al. (2014) proposed a courtyard space comparison prototype similarity method to quantitatively analyze the combination relationship. Pu Xincheng (2012) proposed to measure the positional relationship of courtyard space through the quantitative index of building order.

Table 1. Correlation Quantitative Study of Material Elements in Ancient Town. Source: related research.

Different aspects	Related indicators	method	Related research
Spatial structure	Grid scale, The angle between the axis and a reference object (mountain peak) in the village, Topology depth, Situation of control, Integration, Fractal dimension, Mountain enclosure, openness, average water body width, water body slope, and plant coverage, Spatial texture similarity	Mathematical analysis, spatial syntax analysis, GIS analysis	Zhang Jie et al. (2010), Wang Haofeng et al. (2008), Wang Yansong et al. (2012), Pu Xincheng (2012), Tong Lei (2016)
Land Layout	The situation of mixed land use, Building density, floor area ratio, Building base area, Proportion of different land	Mathematical analysis, GIS analysis	Lin Zhaowu (2015), Ye Yu et al. (2016), Wei Lang et al. (2018)
Street	Street width, The ratio of street length to width, The distance of the building backing from the creek interface, The number of different types of road intersections and their proportion in total road intersections, Road network density, Intersection density, Average block area, Road connectivity, Topological depth	Mathematical analysis, spatial syntax analysis, GIS analysis	Lin Xiaorong et al. (2011), Ding Wowo et al. (2013), Wen Tianrong et al. (2016), Chen Yan (2011), Yuan Sinan (2011), Wang Jianfeng (2004)
Countyard	Similarity of the prototype, Courtyard area, Building size, Quantitative index of building order,	Mathematical analysis, GIS analysis	He Yi et al. (2014), Ye Wei (2013), Pu Xincheng (2012)

2.3.2. Determination of quantitative measurement method

Drawing on the existing related research, in this study, the spatial boundary aspect selects the boundary shape analysis index, the aspect ratio of the boundary closed figure, and the compactness index to evaluate the boundary differentiation.

In terms of land use layout, quantitative analysis is carried out by selecting the indicators of land use function connection, the difference of floor area ratio, and the difference of building density.

In terms of street space, the indicators of the coordination of the overall street space and the difference of the width-to-height ratio of the main roads in the new and old areas are selected for measurement.

In terms of building, the proportion of newly-built modern buildings and the proportion of courtyards that are quite different from traditional architectural combinations are selected for measurement.

The weights of different indicators are all 1. The final result of the quantitative measurement of ancient town morphology is obtained by superimposing different indicators.

Table 2. Measurement Index System of Spatial Morphology. Source: Combine the existing research and the peculiarities of the ancient town.

Aspect	Indicator	Explanation of indicators
Physical boundary	Shape index(a)	$S=\frac{P}{(1.5\lambda-\sqrt{\lambda}+1.5)}*\sqrt{\frac{\lambda}{A\pi}}$, P is the perimeter. A is the area. λ is the ratio of length to width. The minimum value of S is 1. The closer the value of S is to 1, the closer the figure is to the ellipse, the tighter the space boundary. Comparing the shape analysis index of the current situation and the historical boundary, the greater the difference between the two, the greater the spatial differentiation of the ancient town.
	The aspect ratio of the border closed graphics(b)	Comparing the shape analysis index of the current and historical boundaries, the greater the difference between the two, the greater the spatial differentiation of the ancient town.
	Compactness(c)	Compactness==$2\sqrt{\pi A}\ /\ P$. P is the circumference. A is the area. The larger the value is, the more compact it is, and vice versa, the less compactness is. Comparing the compactness of the historical boundary and the current boundary, the greater the difference between the two, the greater the spatial differentiation of the ancient town.
Land Layout	Functional connection of new and old regional land use(d)	Through current research and interviews, the weaker the functional connection between the new and old areas, the greater the degree of differentiation between the new and old areas.
	Differences in floor area ratio between new and old areas(e)	Floor area ratio = building density * average number of floors. Comparing the floor area ratios of the new and old areas, the greater the difference between the two, the greater the degree of differentiation between the new and old areas.
	Differences in building density between new and old areas(f)	The greater the difference in building density between the new and old areas, the greater the difference in the spatial form of the ancient town.
Street	Correlation between global integration and partial integration(g)	According to the calculation by the spatial syntax software, the closer the correlation (R^2) between the two is to 1, the better the coordination of the road network.
	Differences in the width of main roads in the new and old areas(h)	The greater the difference in the width of main streets between the new and old areas, the greater the degree of differentiation
Building	Proportion of traditional buildings (i)	The larger the proportion of traditional buildings in the ancient town, the smaller the differentiation of the ancient town.
	Proportion of	The greater the proportion of courtyards with high similarity to

	courtyards with high similarity to traditional building combination forms (j)	traditional architectural combination forms, the lower the differentiation of spatial forms of ancient towns.

3. Results of quantitative analysis

3.1. Quantitative analysis results of physical boundary

Judging from the changes in the aspect ratio of ancient towns over the years, some ancient towns have gradually increased their aspect ratios, with more obvious banding characteristics, such as Qingmuchuan and Manchuanguan. The aspect ratio of some ancient towns has gradually decreased, and the zoning characteristics have gradually weakened, but the whole still presents cluster settlements with a zonal tendency, such as Fenghuang Town and Shuanghekou Town. From the evolution of boundary compactness index and morphological index, the compactness of the overall boundary of all ancient towns is gradually decreasing.

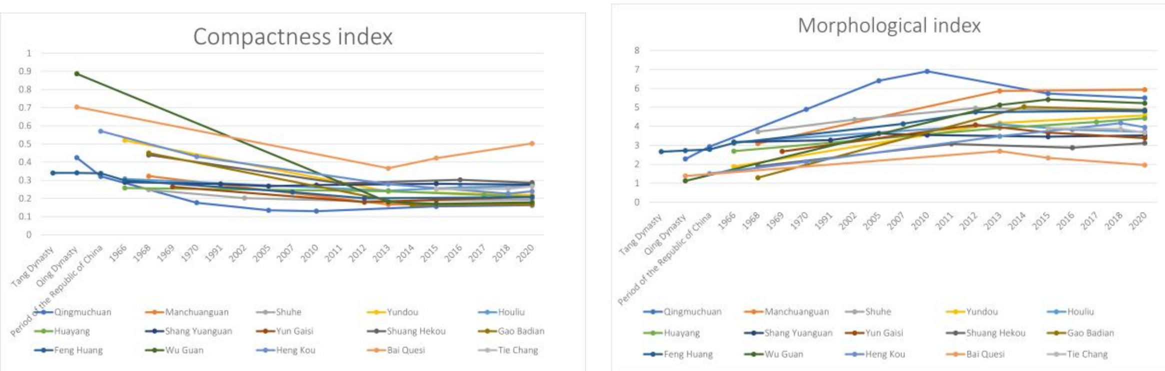


Figure 1. Compactness index and Morphological index. Source: Aerial photos and field investigation.

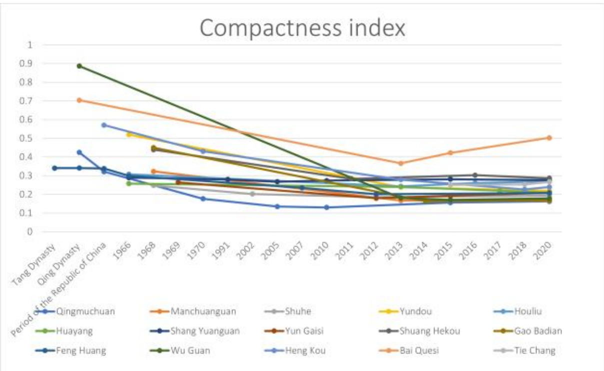


Figure 2. Compactness index. Source: Aerial photos and field investigation.

Table 3. Difference of ratio of length to width(Value A), compactness(Value B) and shape index(Value C) in new and old areas in typical ancient towns in southern Shaanxi. Source: Aerial photos and field investigation.

Town	Qing Muchuan	Man Chuanguan	Shu He	Feng Huang	Wu Guan
Value A	0.42	0.19	0.01	-0.79	0.77
Value B	-0.26	-0.16	-0.06	-0.13	-0.71
Value C	3.22	2.84	1.05	2.10	4.10

3.2. Quantitative analysis results of land Layout

From the perspective of the functional complementarity of land use, Qingmuchuan's new and old regions have the best connectivity, and the new and old regions of Shuhe and Wuguan have the worst connectivity.

From the perspective of the difference in plot ratio between the new and old areas, Shuhe Town has the greatest difference, and Manchuanguan has the least difference. The floor area ratio of the old area of Manchuan Pass is higher than that of the new area, and the average floor area ratio of the new areas of other ancient towns is greater than that of the old area.

From the perspective of the difference in building density, the difference in building density in Shuhe Town is the smallest, and that in Manchuanguan Town is the largest. The building density of the old areas of Qingmuchuan, Manchuanguan, and Fenghuang is greater than that of the new area, and the building density of the new areas of Shuhe and Wuguan is greater than that of the old area.

Table 4. Analysis of the functional connection between the old and the new area of a typical ancient town in southern Shaanxi. Source: Field investigation.

Town	Qing Muchuan	Man Chuanguan	Shu He	Feng Huang	Wu Guan
Functional connection of new and old regional land use	Strong functional complementarity. The old area is developed and utilized as a scenic spot, and a certain number of tourism service facilities are built in the new area.	Strong functional complementarity. Some tourism service facilities are built in the new area, but the use efficiency is relatively low.	Weak functional complementarity. The new area is mainly used as a service center for local residents and has weak contact with the old area.	General functional complementarity. A small number of tourism service facilities will be built in the new area. The old region does not drive the development of the new region.	Weak functional complementarity. The old area has not been developed and utilized, and the connection between new and old areas is weak.
assignment	1	2	4	3	4

Table 5. Differences in floor area ratio between new and old areas (Value A) and Differences in building density between new and old areas (Value B) in typical ancient towns in southern Shaanxi. Source: Aerial photos and field investigation.

Town	Qing Muchuan	Man Chuanguan	Shu He	Feng Huang	Wu Guan
Value A	0.12	-0.72	1.75	0.12	0.48
Value B	-7.02	-11.34	2.13	-5.31	6.65

3.3. Quantitative analysis results of street

From the perspective of the overall coordination of the road network, the roads of Fenghuang Town are relatively well coordinated, while the road networks of Manchuanguan and Shuhe Towns are poor.

However, the correlation coefficients are all far away from 1, indicating that the overall coordination of ancient towns is poor.

Judging from the difference in the aspect ratio of the main roads in the new and old areas, the difference between Shuhe Town and Manchuanguan Town is the smallest.

Table 6. Correlation between global integration and partial integration in typical ancient towns in southern Shaanxi. Source: Aerial photos and field investigation.

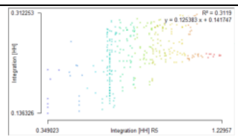
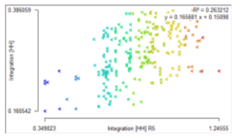
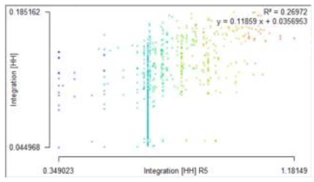
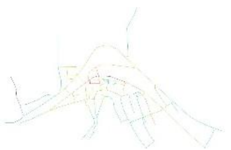
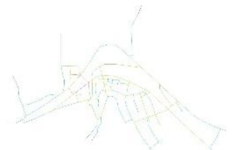
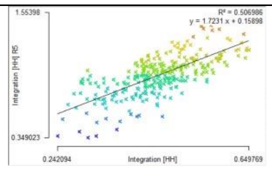
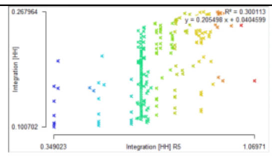
Town	Global integration	Local integration	Correlation
Qing Muchuan(R^2=0.31)			
Man Chuanguan(R^2=0.26)			
Shu He(R^2=0.27)			
Feng Huang(R^2=0.51)			
Wu Guan(R^2=0.30)			

Table 7. The difference between the ratio of road width to street height in the new and old areas in typical ancient towns in southern Shaanxi. Source: Aerial photos and field investigation.

Town	Qing Muchuan	Man Chuanguan	Shu He	Feng Huang	Wu Guan
Value	0.2	0.14	0.42	0.25	0.3

3.4. Quantitative analysis results of building

From the perspective of the proportion of traditional buildings, the proportion of Fenghuang Town is the highest, and that of Manchuanguan Town is the lowest.

In terms of the proportion of courtyards similar to the traditional architectural combination, the proportion of Fenghuang Town is the highest, and the proportion of Manchuanguan Town is the lowest.

Table 8. Proportion of traditional buildings (Value A) and Proportion of courtyards with high similarity to traditional building combination forms (ValueB) in typical ancient towns in southern Shaanxi. Source: Aerial photos and field investigation.

Town	Qing Muchuan	Man Chuanguan	Shu He	Feng Huang	Wu Guan
Value A	14.38%	8.25%	18.48%	20.43%	23.27%
Value B	15.87%	10.32%	13.28%	25.70%	13.28%

4. Conclusion and discussion

4.1 Comprehensive measurement result analysis

The values of different indicators are standardized using spss software, and the indicators are summed. The order of differentiation from strong to weak is Wuguan, Manchuanguan, Shuhe, Qingmuchuan and Fenghuang. The larger difference of Wuguan is mainly due to the larger values of h, i, and j. The large degree of differentiation of Manchuan Pass is mainly due to the large indexes of c, f, and g.

Table 9. Comprehensive measurement result analysis. Source: The author organizes by himself.

Indicator	Qing Muchuan	Man Chuanguan	Shu He	Feng Huang	Wu Guan
a	-1.38	-0.61	0.92	0.15	0.92
b	-0.77	0.12	1.66	-0.77	-0.24
c	0.16	1.46	-1.31	-0.35	0.05
d	0.19	0.68	0.58	-1.75	0.29
e	-0.58	-1.15	1.49	-0.11	0.36
f	0.44	1.49	-0.26	-0.59	-1.08
g	-0.03	0.91	0.41	-1.69	0.41
h	-0.05	-0.72	-1.23	1.02	0.97
i	-0.01	-0.41	-0.80	-0.50	1.72
j	0.48	0.15	-1.40	-0.49	1.25
sum	-1.54	1.92	0.06	-5.08	4.64
Ranking	4	2	3	5	1

4.2 Factors Influencing the Results of Quantitative Measurement of Ancient Town Morphology

4.2.1 Natural environment

Ancient towns are often formed in areas with superior natural conditions. The construction of villages and towns proceeds from reality, conforms to nature, and makes maximum use of terrain and ground conditions to enable people to have a living environment that is warm in winter and cool in summer, convenient for drinking water, well-oriented, sheltered from wind and flood, and is conducive to defense, and has a beautiful environment.

The natural environment mainly affects the spatial layout of the ancient town through the constraints of mountains and rivers, which in turn affects the coordination of the road network, the connection between the new and the old areas, and the shape of the spatial boundary.

4.2.2 Economic development

The industrial structure of the ancient town has undergone tremendous changes during its development. From the general history of the formation of ancient towns, in ancient times, the development of agricultural production and handicrafts in rural areas prompted the emergence of bazaars; the further development of commerce formed a market in the space, and the construction of related commercial shops and warehouses began, while the development of traditional industries Promote the formation of relevant functional land in ancient towns. With the changes in modern transportation and technology, the decline of traditional industries has led to the decline of ancient towns. With the development of cultural tourism and other industries, some ancient towns have been revitalized, which in turn promotes the production of relevant functional land in ancient towns.

The development of the industry will lead to changes in the architectural style, use functions, and development intensity, which will affect the spatial differentiation of the ancient town.

4.2.3 Traffic factor

Traditional ancient towns and external transportation mainly rely on water transportation, official roads, and post stations. The modern mode of transportation has gradually developed from water transportation to road-railway-highway-aviation. The innovation of transportation has led to an increase in transportation efficiency. The internally closed traffic gradually evolved into a regional traffic network.

The new traffic demand will also lead to a decline in the coordination of the traffic network in the old and new areas of the ancient town, and the imbalance of the spatial scale of the streets and lanes in the new area.

4.2.4 Changes in residents' needs

The needs of the residents in the village are mainly reflected in the pursuit of modernization of the quality of life, which has led to a continuous increase in the space demand for infrastructure and public service facilities. On the other hand, it is reflected in the demand of urban residents for tourism, leisure and vacation, which has led to the enthusiasm for rural pastoral life and traditional settlement tourism, which in turn led to an increase in the demand for the construction of tourist service facilities by ancient town residents.

Changes in residents' needs will lead to changes in the function of land use, development intensity, architectural style, and architectural composition in the space, which in turn affects the spatial differentiation of the ancient town.

4.3 Guidance for the development of the spatial form of ancient towns

4.3.1 Development guidance of physical boundaries

The growth of spatial land in ancient towns should be expanded in an orderly manner in accordance with the logic of spatial evolution, so as to maintain the style of the ancient town to the greatest extent. It also controls the development direction, land use scale, and boundary shape of the ancient town.

4.3.2 Development guidance of land use layout

The current elements of the ancient town should be organized organically in the land use layout. Manage and control the building density, floor area ratio, and usage functions of different blocks.

4.3.3 Development guidance of street

Street space should be optimized and adjusted to improve the coordination of the road network and improve the efficiency of use. At the same time, the size of streets and lanes in the new and old areas is controlled.

4.3.4 Development guidance of building

The building should control the style and appearance of the new area and the combination of buildings. From the perspective of the overall courtyard form and order, the overall layout of the courtyard should abide by the main axis of the Ming and Qing dynasties, and fully consider the relationship with the surrounding mountains on the premise of meeting modern needs. From the perspective of the renewal of traditional courtyards and the construction of new courtyards, traditional courtyards should be repaired based on the spatial layout of traditional courtyards; newly-built courtyards should inherit the space genes of traditional courtyards on the basis of meeting the needs of modern residents, through the horse head wall The use of historical elements of the courtyard, such as the courtyard space, and patio space, maintains the same structure of the new building and the original one.

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