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Study on the Spatial Form and Elements of Huizhou Traditional Residential Courtyards Based on Clustering Analysis

SHAO Wei¹, LI Zao², YE Maosheng³

Author Affiliations 1 PhD Candidate, School of Architecture and Art, Hefei University of Technology; 2 Professor, corresponding author, Email: lizao72@hotmail.com, School of Architecture and Planning, Anhui Jianzhu University; 3 Lecturer, School of Humanities, Chaohu University

ABSTRACT: The study of traditional residential courtyards promotes the protection and renovation of traditional residences and enriches the spatial expression of new residential courtyards. As an organic component of the traditional residence, the courtyard space plays a role in improving, amplifying, and complementing the function of the main building space. This study investigated 63 Huizhou traditional residential courtyards, including those in Xidi, Hongcun, Nanping and Pingshan. The basic architectural information was first examined, and a field survey was undertaken to disclose the relationship between the courtyard and the main building space. The morphological characteristics of the courtyard were described through five dimensions: area, area ratio, aspect ratio, saturation, and boundary coefficient. Then, the courtyard space was classified through clustering analysis. Meanwhile, the courtyards' location and characteristics of elemental organization within different morphological types were considered.

The study shows that the traditional Huizhou courtyards can be classified into four types based on the quantitative clustering characteristics of spatial morphology, namely: medium-scale square, medium-scale strip, medium-scale irregular, and large-scale complex. Firstly, medium-scale square courtyards are the most common type, sharing the same proportion and form as the main building space. This type of courtyard offers a sense of stability and regularity. Moreover, they are typically located in the front and back of the residence. They include stone benches and other elements arranged with greenery, water, arches, secondary contours, and other elements, enriching the landscape levels and expanding the spatial function. Secondly, medium-scale strip courtyards mostly appear in large residential groups, which organize people's routes, depicting the spatial dynamism and directions. They mainly incorporate structures and arches, sometimes combined with greenery, plaques, stone tables, and openwork windows. Such structures weaken the sense of enclosure and insecurity generated by the long and narrow space. Thirdly, medium-scale irregular courtyards present irregular spatial forms in the front and side of the residence due to irregular land conditions and regular main building plans, often serving as a highlight of the residential space. The configuration of greenery, water, openwork windows, and their mutual combinations is mainly used to weaken the irregularity of space through spatial remediation and the creation of a visual focus. Finally, large-scale complex courtyards are predominantly located in backyards and serve as recreational areas and living spaces, enabling people to get close to nature. The configuration of spatial factors is mainly composed of natural leisure elements, such as water and stone benches. Larger-scale courtyards usually combine with greenery elements to provide the house owner with a comfortable and private living scene.

The current study clarified the typological characteristics of courtyard spatial forms through clustering analysis. It also discussed the spatial form and element organization of the traditional Huizhou courtyard. On this basis, the relationships among the courtyard, the building's main body,

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and the composition and organization of environmental elements were investigated and classified. The research conclusions can provide a theoretical basis for maintaining traditional residential courtyard forms and preserving their authenticity, as well as a reference for creating new residential courtyard spaces in Huizhou.

KEYWORDS: Huizhou traditional residence; courtyard; clustering analysis; morphological quantification; elements

Introduction

As an organic component of Huizhou traditional residences [1], the courtyard space is characterized by being “formed based on the site, adapted to the context, and following principles without fixed modes [2]”, conveying the cultural characteristics of “farming-reading” and the integration of Confucian scholarship and commerce. It reflects the purpose and belief of life under the Huizhou cultural environment and plays a role in reinforcing, amplifying, and supplementing the function of the main building. Against the backdrop of changes in traditional social structure and the rise of village tourism [3], traditional culture and the “spirit of place” are gradually waning, the spatial pattern of residential courtyards is being destroyed, and the courtyard landscape is gradually being detached from traditional society [4,5]. In newly constructed residential courtyards, there are also issues where regional culture is becoming merely symbolic and superficial [6].

In the study of restoring spatial patterns and reconstructing the cultural connotations of landscapes, researchers mostly base their restoration efforts on residents’ oral accounts, the regional features of courtyards, and the original building sites for restoration [7]. Previous studies on courtyard morphology have mostly focused on its relationship with the main building’s orientation, form, and scale. Courtyard spaces are mostly located in the front, back, and side of Huizhou traditional residences, with free forms and variable patterns [8]. Studies on the elements of Huizhou courtyards show that the courtyards are often decorated with landscape elements such as openwork windows, arches, rocks, and plants to strengthen the connection between the courtyard space and the outside world as well as nature [9]. However, the protection and utilization of courtyard space still reveal problems such as fragmented theories and insufficient technical methods [10]. Based on the study of regional landscape features, this paper combines morphological research with element organization to

explore the location and element features of residential courtyards of different morphological types. This helps to grasp the internal causes of courtyard space organization, offers quantitative reference for courtyard space research, and thereby provides guidance for the restoration and utilization of regional landscape features and cultural connotations in traditional residential space, and enriches the expression of new residential courtyard space [11, 12].

1 Overview of Huizhou traditional residential courtyards

1.1 Formation background of courtyard spaces

Huizhou villages are situated amidst picturesque mountains and rivers, with buildings and streets arranged in a staggered pattern, accompanied by abundant and beautiful flowers, trees, and vegetation. Influenced by the architectural philosophy of “suitably selecting the site and appropriately composing the garden,” Huizhou traditional residential courtyard spaces have been formed within a limited space to express an emotional attachment to natural landscapes. The courtyard space serves not only as a transition connecting streets with the building interior and an outward extension of the architectural space, but also as an expression of the owner’s emotions. Influenced by the overall layout of the village, the direction of the streets and alleys, and the shape of the houses, the village, within its limited space, expresses the “farming-reading” tradition of scholarly families and the idealistic pursuit of a “Peach Blossom Spring” (Utopia). Therefore, the study of the typology of Huizhou traditional residential courtyard spaces is an extension of the study of village street space and a refinement of the study of residential morphology. It also provides theoretical support for understanding the relevant aspects of the transition and connection of village residential clusters.

1.2 Case selection

The study conducted field research in Huizhou traditional villages such as Xidi, Hongcun, Nanping, and Ping-

shan. These villages are relatively well protected and developed, and the house layout and configuration of elements are well preserved [13]. The survey mainly focused on key protected buildings in the village and evaluated the representativeness of the buildings and courtyard spaces from the dimensions of their historical significance, integrity, artistry, and authenticity [14]. Subsequently, through on-site measurement and aerial photography, the plans of

63 representative traditional Huizhou residential courtyards were obtained (Figure 1). Basic information on the courtyard space was obtained through interviews and literature reviews (Table 1). Based on the relative relationship between the courtyard and the main hall's orientation, the courtyard space was classified into three categories: front yard, back yard, and side yard, with 37 front yards, 14 back yards, and 12 side yards.

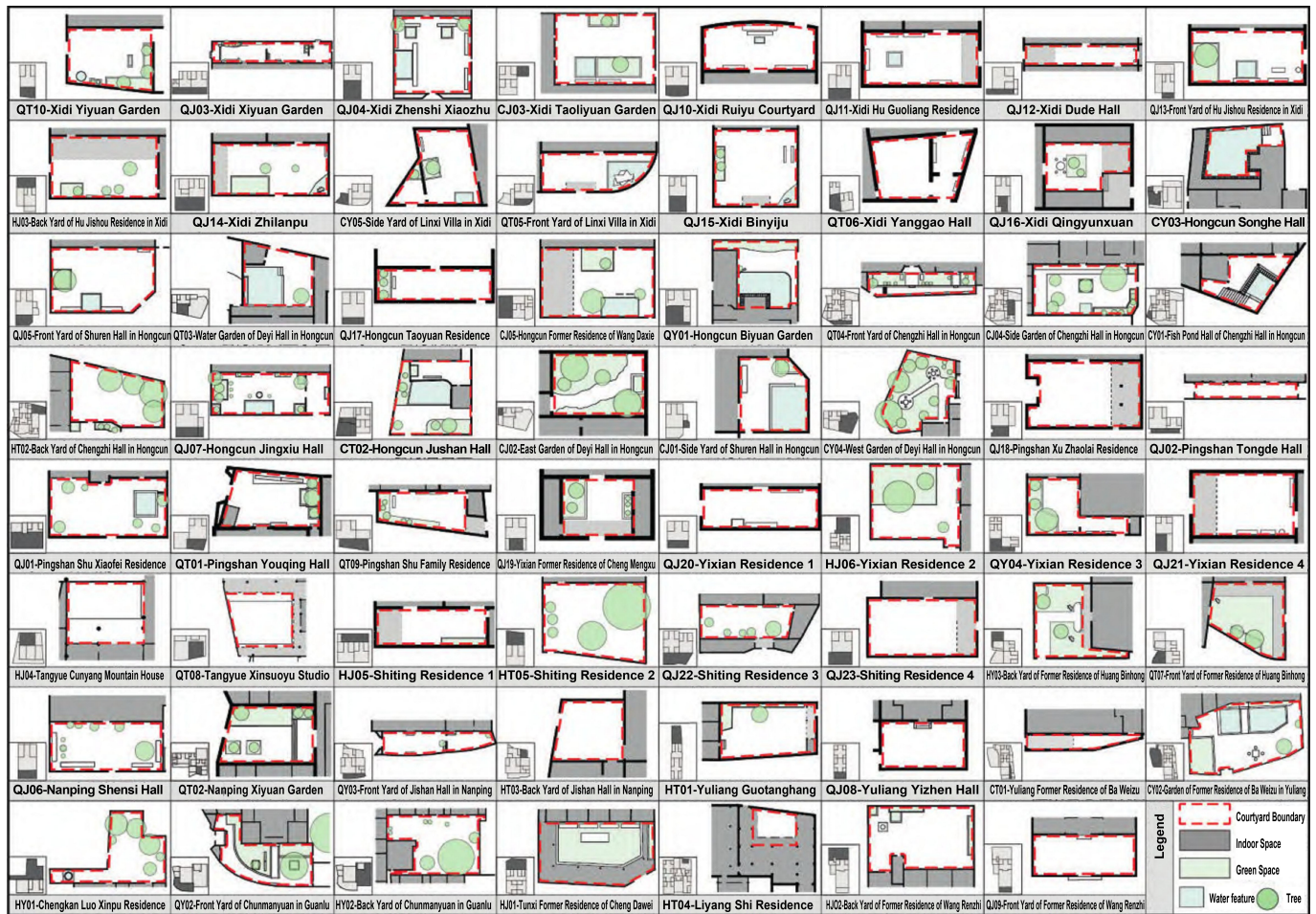


Figure 1 Selection of sample courtyards

1.3 Extraction of spatial elements

The arrangement and combination of courtyard elements greatly influence the landscape impression of the courtyard space and further serve as an organic part of cultural construction. Huizhou Traditional residences typically have small courtyards, which can create a feeling of oppression and confinement. The arrangement of spatial elements plays a role in enhancing the openness and richness of the courtyard space (Figure 2). Spatial elements are

divided into two types: planar elements and vertical elements. Planar elements mainly include greenery, water, stone tables, benches, structures, and wells. Among them, structural elements include porches, bridges, and steps, which are collectively referred to as structures. Vertical elements include openwork windows, arches, plaques, and secondary contours. "Secondary contours" refer to temporary external attachments to the building [15], including lanterns, couplets, signs, and so on. These spatial elements,

together with the courtyard space, constitute the unique Huizhou traditional residential courtyard, serving as a medium for ancient Huizhou literati to express their ideals and sentiments.

Table 1 Basic information of courtyard spaces

Code	Courtyard Name	Conservation Status	Era	Village	Protection Level	Current Use
QT10	Yiyuan Garden	Excellent	Qing Dynasty	Xidi	National Key Cultural Relics Protection Unit (Xidi Ancient Buildings)	Residential
QJ03	Xiyuan Garden	Excellent	Qing (Daoguang)			Tourism
QJ04	Zhenshi Xiaozhu	Excellent	Qing (Daoguang)			Residential
CJ03	Taoliyuan Garden	Excellent	Qing (Xianfeng)			Tourism
QJ10	Ruiyu Courtyard	Excellent	Qing (Xianfeng)			Tourism
QJ11	Hu Guoliang Residence	Excellent	Qing Dynasty			Residential
QJ12	Dude Hall	Excellent	Late Ming			Guesthouse
QJ13	Hu Jishou Residence (Front Yard)	Good	Qing Dynasty			Residential
HJ03	Hu Jishou Residence (Back Yard)		Qing Dynasty			Residential
QJ14	Zhilanpu	Good	Qing Dynasty			Guesthouse
CY05	Linxi Villa (Side Yard)	Excellent	Qing (Daoguang)			Guesthouse
QT05	Linxi Villa (Front Yard)	Excellent	Qing (Daoguang)			Guesthouse
QJ15	Binyiju	Good	Qing Dynasty			Guesthouse
QT06	Yanggao Hall	Excellent	Ming (Wanli)			Guesthouse
QJ16	Qingyunxuan	Excellent	Qing (Tongzhi)			Residential
CY03	Songhe Hall	Excellent	Qing (Tongzhi)			Hongcun
QJ05	Shuren Hall (Front Yard)	Excellent	Qing (Tongzhi)	Residential		
CJ01	Shuren Hall (Side Yard)	Excellent	Qing (Tongzhi)	Residential		
QJ17	Taoyuan Residence	Excellent	Qing (Xianfeng)	Tourism		
CJ05	Former Residence of Wang Daxie	Good	Qing (Daoguang)	Tourism		
QY01	Biyuan Garden	Good	Late Ming	Guesthouse		
QT04	Chengzhi Hall (Front Yard)	Excellent	Qing (Xianfeng)	Tourism		
CJ04	Chengzhi Hall (Side Garden)	Excellent	Qing (Xianfeng)	Tourism		
CY01	Chengzhi Hall (Fish Pond Hall)	Excellent	Qing (Xianfeng)	Tourism		
HT02	Chengzhi Hall (Back Yard)	Excellent	Qing (Xianfeng)	Tourism		
QJ07	Jingxiu Hall	Excellent	Qing (Daoguang)	Tourism		
CT02	Jushan Hall	Excellent	Qing (Xianfeng)	Guesthouse		
CJ02	Deyi Hall (East Garden)	Excellent	Qing (Jiaqing)	Residential		
QT03	Deyi Hall (Water Garden)	Excellent	Qing (Jiaqing)	Residential		
CY04	Deyi Hall (West Garden)	Excellent	Qing (Jiaqing)	Residential		
HJ04	Cunyang Mountain House	Excellent	Qing (Jiaqing)	Tangyue Village	National Key Cultural Relics Protection Unit (Tangyue Ancient Residences)	Display
QT08	Xinsuoyu Studio	Excellent	Qing (Jiaqing)	Display		
QJ18	Xu Zhaolai Residence	Excellent	Qing Dynasty	Pingshan Village	Anhui Provincial Cultural Relics Protection Unit (Pingshan Ancient Buildings)	Residential
QJ02	Tongde Hall	Excellent	Qing Dynasty			Residential
QJ01	Shu Xiaofei Residence	Good	Qing Dynasty			Guesthouse
QT01	Youqing Hall	Excellent	Qing (Daoguang)			Tourism
QT09	Shu Family Residence	Good	Qing Dynasty			Residential

(Continued)

Code	Courtyard Name	Conservation Status	Era	Village	Protection Level	Current Use
QJ19	Former Residence of Cheng Mengxu	Excellent	Qing Dynasty	Yixian Ancient City	Yixian County Cultural Relics Protection Unit	Residential
QJ20	Residence 1	Excellent	Qing Dynasty		Yixian Registered Immovable Cultural Relics	Residential
HJ06	Residence 2	Good	Qing Dynasty		Yixian County Cultural Relics Protection Unit	Vacant
QY04	Residence 3	Good	Qing Dynasty		Yixian Historical Architecture	Residential
QJ21	Residence 4	Excellent	Qing Dynasty		Yixian County Cultural Relics Protection Unit	Residential
HJ05	Residence NO. 1	Good	Qing Dynasty	Shiting Village	2nd Batch of Traditional Chinese Villages List	Residential
HT05	ResidenceNO. 2	Excellent	Qing Dynasty			Residential
QJ22	ResidenceNO. 3	Excellent	Qing Dynasty			Residential
QJ23	ResidenceNO. 4	Good	Qing Dynasty			Residential
HY03	Former Residence of Huang Bin-hong (Back)	Excellent	Qing (Kangxi)	Tandu Village	Anhui Provincial Cultural Relics Protection Unit	Exhibition
QT07	Former Residence of Huang Bin-hong (Front)	Excellent	Qing (Kangxi)			Exhibition
QJ06	Shensi Hall	Excellent	Qing (Kangxi)	Nanping Village	National Key Cultural Relics Protection Unit (Nanping Ancient Buildings)	Residential
QT02	Xiyuan Garden	Good	Qing (Qianlong)			Residential
QY03	Jishan Hall (Front Yard)	Excellent	Qing (Guangxu)			Residential
HT03	Jishan Hall (Back Yard)	Excellent	Qing (Guangxu)			Residential
HT01	Guotanghang	Good	Qing Dynasty	Yuliang Village	Shexian County Cultural Relics Protection Unit	Tourism
QJ08	Yizhen Hall	Excellent	Republic of China		Shexian County Cultural Relics Protection Unit	Residential
CT01	Former Residence of Ba Weizu	Excellent	Ming (Wanli)		Anhui Provincial Cultural Relics Protection Unit	Exhibition
CY02	Garden of Former Residence of Ba Weizu	Excellent	Ming (Wanli)			Exhibition
HY01	Luo Xinqu Residence	Good	Qing Dynasty	Guanlu Village	—	Residential
QY02	Chunmanyuan (Front Yard)	Excellent	Qing (Qianlong)		Residential	
HY02	Chunmanyuan (Back Yard)	Excellent	Qing (Qianlong)		Anhui Provincial Cultural Relics Protection Unit	Residential
HJ01	Former Residence of Cheng Dawei	Excellent	Ming (Hongzhi)	Tunxi District	National Key Cultural Relics Protection Unit	Exhibition
HT04	Shi Residence	Excellent	Late Qing	Liyang Old Street	Huangshan Municipal Cultural Relics Protection Unit	Exhibition
HJ02	Former Residence of Wang Renzhi (Back)	Good	Early Qing	Shexian Ancient City	Shexian County Cultural Relics Protection Unit	Exhibition
QJ09	Former Residence of Wang Renzhi (Front)	Good	Early Qing		Shexian County Cultural Relics Protection Unit	Exhibition



Legend 1. Greenery 2. Water feature 3. Stone table 4. Stone bench 5. Structure 6. Well 7. Openwork window 8. Arch 9. Plaque 10. Secondary contour

Figure 2 Extraction of courtyard space elements

2 Quantitative analysis of courtyard space form

2.1 Principles of courtyard space quantification

Quantitative indicators related to the size and morphological proportions of courtyard spaces were established to describe the courtyard spaces of traditional residences. The study analyzes five dimensions: courtyard area, area ratio, aspect ratio, saturation, and boundary coefficient, aiming to grasp the morphological characteristics of Huizhou traditional residential spaces, such as size and proportion, from a quantitative perspective.

The dimensions of the courtyard and main building were obtained through on-site measurement (Figure 3). The area of the courtyard and the ratio of the courtyard space to the building footprint were calculated to assess the scale, size and proportional relationship of the courtyard

space to the main building. In graphic morphology research, the ratio of the projected area of a graphic to the area of its circumscribed rectangle is often used to define the degree to which it fills the circumscribed rectangle [16]. The study uses the ratio of the area of the courtyard to the area of the circumscribed rectangle as the saturation degree. The higher the value, the more saturated the courtyard space is. In order to supplement the saturation degree in reflecting the indentation and inclination of the courtyard outline, the ratio of the perimeter of the courtyard to the perimeter of the circumscribed rectangle is used as the boundary coefficient. The closer the value is to 1, the more regular the courtyard outline is. The aspect ratio of the circumscribed rectangle is used as the aspect ratio of the courtyard space.

	Courtyard Code	QJ01	QJ02	QJ03	QJ04	QJ05	QJ06	QJ07	QJ08	QJ09	QJ10	QJ11	QJ12	QJ13	QJ14	QJ15	
	Area(m ²)	192.2	81.7	126.5	61.7	63.1	25.2	71.2	54.5	33.1	21.9	23.2	30.3	24.5	78.5	78.0	
	Area ratio	0.62	0.22	0.32	0.52	0.11	0.18	0.22	0.2	0.09	0.21	0.34	0.29	0.11	0.42	0.46	
	Aspect ratio	1.96	5.96	5.35	1.01	1.62	2.24	2.74	1.74	2.44	2.41	2.07	5.02	2.05	2.17	1.09	
	Saturation	0.97	1	1	1	0.97	1	1	1	1	0.96	1	1	1	1	1	
	Boundary coefficient	1.04	1	1	1	0.96	1	1	1	1	0.97	1	1	1	1	1	
	QJ16	QJ17	QJ18	QJ19	QJ20	QJ21	QJ22	QJ23	QT01	QT02	QT03	QT04	QT05	QT06	QT07	QT08	
	19.9	22.2	59.5	12.6	24.2	22.4	96.0	63.7	51.3	32.2	80.8	111.1	35.2	18.7	93.4	29.5	
	0.24	0.28	0.25	0.24	0.28	0.33	0.28	0.32	0.24	0.06	0.17	0.1	0.13	0.17	0.21	0.32	
	1.81	3.23	1.74	1.2	2.98	1.57	2.83	1.85	1.77	1.63	1.07	4.28	2.81	1.52	1.08	1.23	
	0.77	1	0.95	1	1	1	0.96	1	0.88	0.93	0.89	0.93	0.77	0.68	0.85	0.91	
	1	1	1.1	1	1	1	0.98	1	0.94	0.95	0.95	0.97	0.93	0.91	0.9	0.95	
	Area ratio = $\frac{\text{Courtyard area}}{\text{Building footprint}}\%$	QT09	QT10	QY01	QY02	QY03	QY04	HJ01	HJ02	HJ03	HJ04	HJ05	HJ06	HT01	HT02	HT03	HT04
	0.37	0.35	0.42	0.22	0.15	0.32	0.31	0.31	0.33	0.24	0.29	0.41	0.42	0.12	0.09	0.03	
	2.03	1.44	1.24	1.41	4.18	2	1.81	1.59	1.7	1.24	2.78	1.08	1.68	1.37	1.19	1.82	
Aspect ratio = $\frac{\text{Length of circumscribed rectangle}}{\text{Width of circumscribed rectangle}}\%$	0.81	1	0.76	0.6	0.85	0.59	0.94	0.94	1	1	1	0.92	0.95	0.81	0.93	0.89	
0.94	0.99	0.98	0.94	0.95	1	0.95	1.09	1	1	1	1	0.98	0.93	0.96	0.97		
Saturation = $\frac{\text{Courtyard area}}{\text{Area of circumscribed rectangle}}\%$	HT05	HY01	HY02	HY03	CJ01	CJ02	CJ03	CJ04	CJ05	CT01	CT02	CY01	CY02	CY03	CY04	CY05	
197.2	145.6	272.2	76.4	16.4	27.1	78.9	146.2	186.5	25.9	119.0	38.0	252.7	99.3	225.6	34.7		
0.4	0.51	0.37	0.17	0.11	0.06	0.19	0.12	0.38	0.04	0.27	0.04	0.29	0.21	0.47	0.22		
Boundary coefficient = $\frac{\text{Courtyard perimeter}}{\text{Perimeter of circumscribed rectangle}}\%$	1.27	1.61	1.64	1.25	1.08	1.38	1.4	2.03	1.62	6.57	1.11	1.6	1.54	1.47	1.11	1.28	
0.92	0.53	0.8	0.64	0.96	1	1	0.99	1	0.86	0.92	0.69	0.8	0.77	0.71	0.64		
0.97	0.99	1.14	0.99	0.96	1	1	0.98	1	0.96	0.96	0.86	0.93	0.98	0.87	0.93		

Figure 3 Quantitative description of the sample courtyard

2.2 Quantification of the morphological characteristics of courtyard spaces

By conducting statistical analysis on five aspects of the

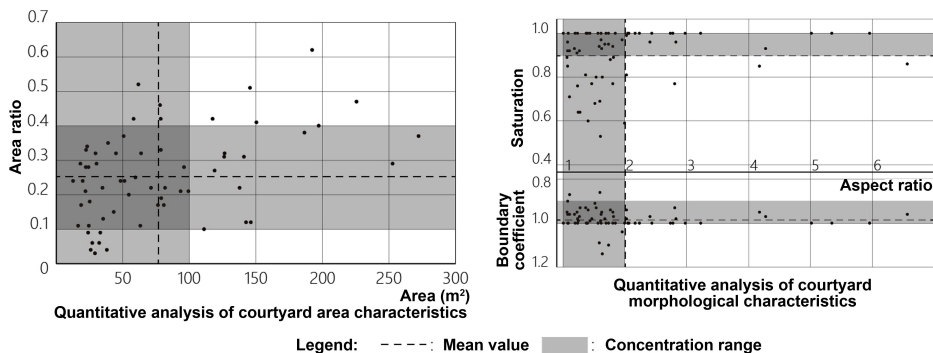


Figure 4 Analysis of the quantitative coefficients of the courtyard

In terms of area, the average area of the sample courtyards is 78.2 m², and most of them are under 100 m². Courtyards within 50 m² account for 42.9% of the sample courtyards, and courtyards between 50 m² and 100 m² account for 30.2%. It can be seen that, as a supplement to the main building, the courtyard space is generally smaller in scale, and its spatial scale is intimate and human-scaled. There are also some large courtyard spaces. These courtyards have a weaker sense of enclosure, are closer to nature, and can serve as places for viewing, rest, and daily life, enriching the lifestyle of the homeowners. In terms of area ratio, Huizhou traditional residences vary in size, and the constraints on courtyard construction are different, thus showing considerable variation. The average area ratio of courtyard space was 0.26, with 73% of the sample courtyards having an area ratio between 0.1 and 0.4. Among these, the ratio between 0.2 and 0.3 accounted for the largest proportion (31.7%).

A percentage higher than 0.4% or lower than 0.1% is less common. The analysis shows that, in courtyard construction, designers not only made use of limited residual spaces but also deliberately reserved moderately sized courtyards that are proportionate to the main building, thereby enriching the rhythm of the spatial sequence. However, outside of this general pattern, the survey found a small number of samples with a small building footprint but a large courtyard area, or a large building footprint but a small courtyard space. For these types of courtyards, it is necessary to consider the special land use conditions and

sample courtyards—area, area ratio, aspect ratio, saturation, and boundary coefficient—the general rules of the courtyard spatial arrangement can be grasped as a whole (Figure 4).

the living background of the homeowner.

In terms of aspect ratio, the average aspect ratio of the sample courtyards is 2, and most of them are between 1 and 2, accounting for 68.3% of the sample courtyards. Those with an aspect ratio greater than 2 are relatively few. The results indicate that rectangular courtyard spaces ensure a strong sense of centrality and provide relatively uniform viewing distances for resting and strolling, contributing to a stable and comfortable spatial perception.

In terms of saturation, the mean value is 0.9, and 65.1% of the sample courtyards are concentrated between 0.9 and 1. It can be observed that, influenced by the traditional construction concepts of regularity and stability, and by introducing the regular order of traditional architectural space into the courtyard, most courtyard spaces are regular and full. From the perspective of the boundary coefficient, courtyards with a value less than 1 account for 52.4% of the sample courtyards, of which 49.2% are in the range of 0.9 to 1. The findings suggest that most courtyards adopted inclined or bent boundary treatments to adapt to land-use constraints during construction, although these adjustments were generally controlled within a limited range.

3 Courtyard feature analysis based on clustering analysis

3.1 Classification and analysis of courtyard forms

Clustering analysis, as a multivariate statistical method, splits or aggregates data according to the data connection rules to find natural groups in the dataset [17]. The distance between any two points within the

same group is less than the distance between any two points in different groups; data within a group are similar, while data in different groups are dissimilar. The study provides a quantitative description of the courtyard space of Huizhou traditional residences from five dimensions: area, area ratio, aspect ratio, saturation, and boundary coefficient. In the clustering analysis, the quantification coefficients of the selected 63 Huizhou

traditional residential courtyard samples were first standardized using a standard deviation of 1 to eliminate the influence of different units of measurement. Subsequently, Ward's method was employed for cluster analysis. The classification was determined by observing the clustering results, and the types were named according to the distribution characteristics of the initial variables within each classification result (Figure 5).

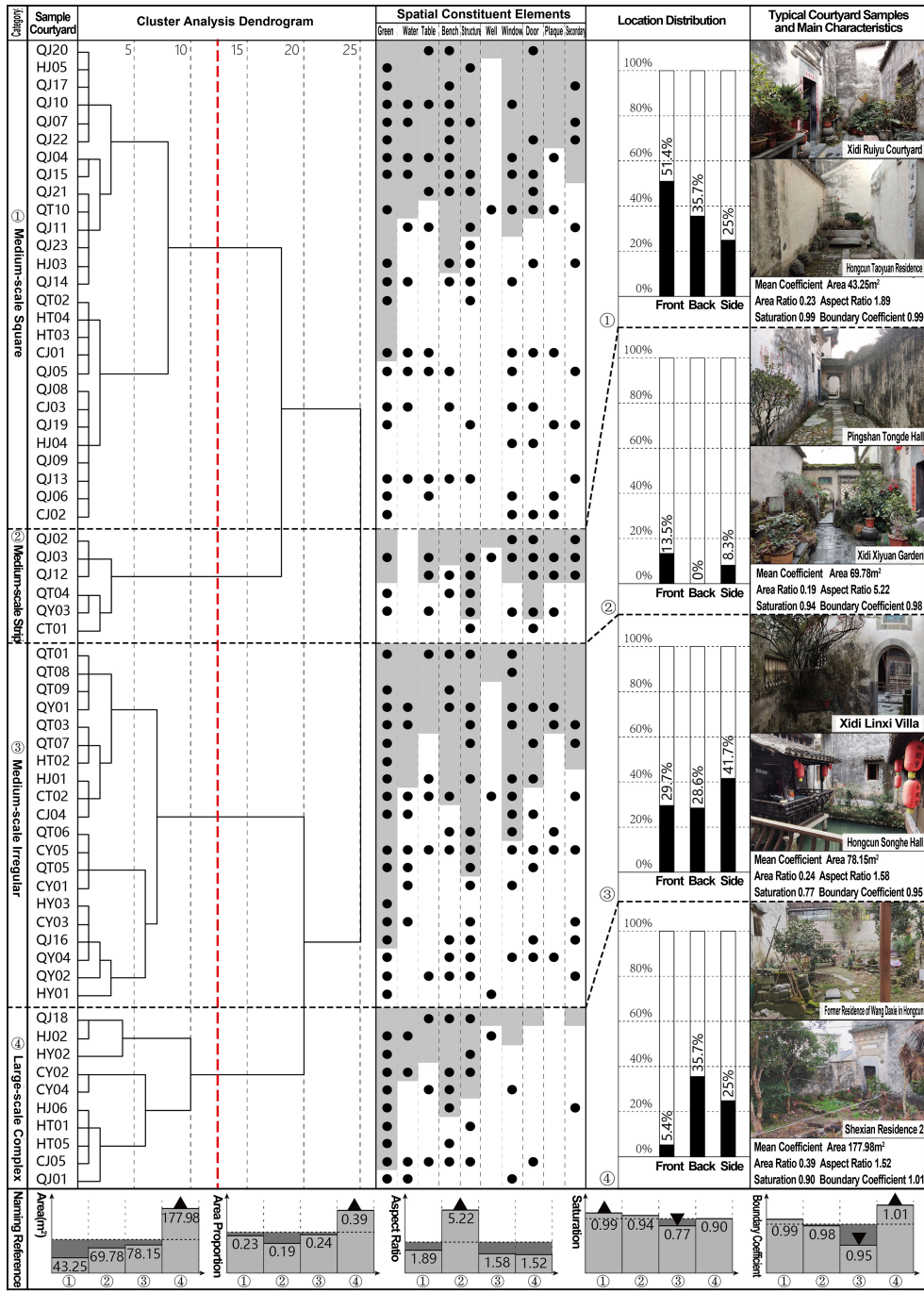


Figure 5 Comparison of planar morphological clustering and spatial organization

The courtyard spaces of traditional Huizhou residences can be broadly categorized into four types:

Type1, represented by Ruiyu Courtyard in Xidi and Taoyuan Residence in Hongcun, has the highest average saturation (0.99) and a relatively low average area (43.25 m²) among the four types, and is therefore named “medium-scale square” courtyards. This type of courtyard appeared most frequently in the sample, accounting for 42.9% of the courtyards.

Type2, represented by Tongde Hall in Pingshan and Xiyuan Garden in Xidi, has the highest average aspect ratio (5.23) and a relatively low average area (69.78 m²) among the four types, and is therefore named “medium-scale strip” courtyards. This type of courtyard appeared least frequently in the sample, accounting for 9.5% of the courtyards.

Type3, represented by the side yard of Xidi Linxi Villa and Songhetang in Hongcun, have the lowest average saturation (0.77), average boundary coefficient (0.95), and relatively low average area (78.15 m²) among the four types of courtyards. Therefore, they are named “medium-scale irregular” courtyards, accounting for 31.7% of the sample.

Type4, represented by the former residence of Wang Daxie in Hongcun and Shexian Folk House 2, have the highest average area (177.98 m²), average area ratio (0.39), and average boundary coefficient (1.01) among the four types of courtyards. Therefore, they are named “large-scale complex” courtyards, which are less common in the sample, accounting for 15.9%.

Courtyard design in Huizhou traditional residences demonstrates an emphasis on human-scaled spaces and the use of regularity to enhance spatial order. Due to land constraints, many irregular courtyard spaces have emerged. By cleverly utilizing these spaces and seeking variations within the balanced and symmetrical form of traditional residences, these spaces often become focal points of the living environment. Large-scale complex courtyards often have high requirements for land conditions. In addition to organizing circulation, they can also serve as places for

viewing and relaxation, providing a place for homeowners to enjoy the natural scenery. Medium-scale strip courtyards generally serve to organize and connect circulation, but because their narrow and long spaces can easily create a sense of insecurity, they are generally less common.

3.2 Correlation analysis between morphological type and location

In Huizhou traditional residences, courtyard spaces are generally divided into front yards, back yards, and side yards according to their relative position and orientation to the main hall. The front yards appeared most frequently, accounting for 58.7% of the sample courtyards, followed by the back yards, accounting for 22.2%, while the side yards appeared the least frequently, accounting for 15.9%. As the starting point and transition of the architectural spatial sequence, the front yard is the focus of courtyard space creation. The axial relationship of the main building extends to the courtyard space, playing a role in highlighting the family status and symbolizing lineage. In addition, the front yard can block wind and sand, welcome sunlight, form a comfortable climate, and satisfy the feng shui pursuit of “gathering wind and accumulating qi” [18]. Because the back yard is located at the end of the building’s flow, it is a more private space and serves less as a circulation area and more as a space for rest and daily life. There are two common types of side yards. One type involves creating a landscape design for the empty space within the site, transforming it into a scenic courtyard. Another type is arranged on one side of the main building, and these courtyards serve both as scenic attractions and circulation hubs.

In terms of the location distribution of courtyards in the four categories, the front yard is the most common in medium-scale square courtyards, followed by the back yard, while the side yard is less common. Among these, the front yard had the largest distribution in this type of yard, accounting for 51.4% of the total front yards sampled. In the medium-scale strip courtyard samples, the front yard was the most common, followed by the side yard, and no back yards were found. Among the samples

of medium-scale irregular courtyards, the front yard appeared the most, followed by the side yard, and the back yard appeared the least. Specifically, the distribution of side yards in this category accounts for 41.7% of the total side yard sample, which is the highest proportion for side yards across all categories and exceeds the proportional representation of front and back yards within this category relative to their respective total samples. In large-scale complex courtyards, the back yard appears most frequently, followed by the side yard, and the front yard appears least frequently. These types of courtyards are mostly residential courtyards with relatively simple space requirements, resulting in complex boundary forms. Therefore, they are mainly distinguished from the other three categories by area metrics.

The analysis reveals that medium-scale square courtyards are predominantly used as introductory spaces, supplementing the outdoor area in front of the main building. Their human-scaled spatial dimensions and square spatial layout provide an opportunity to appreciate and get close to nature, while also providing a comfortable spatial experience. Medium-scale strip courtyards, due to their long and narrow spatial characteristics, often express directionality and give the courtyard space a sense of dynamism. They are suitable for use as front yard spaces in larger residential complexes for circulation organization. Due to the strict land use conditions in Huizhou, side yards are often located at the corners of the land. Compared with courtyards in other locations, they are more affected by the terrain and present a low-saturation form. This unsaturated spatial form breaks the rigidity of the architectural composition, making the overall space more dynamic and lively. Due to the private spatial attributes of the back yard and its functions of viewing, resting, and living, the space requirements are relatively large, which is more in line with the concept of “emulating heaven and earth, and imitating the four seasons”. However, under the condition of tight land use, it is not easy to create such a large-scale complex courtyard in the front yard.

3.3 Correlation Analysis between morphological types and environmental Factors

From the overall distribution of elements, greenery

elements appeared most frequently in the sample courtyards. The creation of courtyard spaces emphasizes the concepts of “learning from nature” and “harmony between man and nature”. Through the observation of natural scenery and phenomena in the courtyard, people can feel the vitality of all things, think about the connection between life and nature, and express their moral ideals and life pursuits through images such as “serene bamboo” and “orchid in an empty valley”. In addition, in a space rich in natural elements, people’s attention is easily diverted, which can foster positive emotions [19]. Thus, the courtyard space can also play a role in mutual nourishment between people and nature. As the main source of drinking water for villagers, wells are mostly located in the village center or nearby streets and alleys combined with open spaces, so they rarely appear in the courtyards of residential houses [20]. The distribution and combination patterns of elements differ in the four types of courtyards. The proportion of each type of courtyard containing various environmental elements is used as the distribution ratio of the elements to express the distribution of elements in each type of courtyard (Figure 6).

Among medium-scale square courtyards, those with water features, structures, or wells accounted for 37%, 40.7%, and 3.7% of the sample, respectively, which is a relatively low proportion. These results indicate that medium-scale square courtyards, due to their relatively limited spatial scale, show less need for additional structures to reinforce territorial definition or enrich spatial layering and enclosure. In fact, they may even exacerbate the feeling of crampedness in the courtyard space. In addition, these courtyards have fewer living functions and are mostly front yards that serve more functions of circulation organization and display. As a result, elements of water wells and water features are less common.

In medium-scale strip courtyards, those with structures, stone tables, arches, plaques, or secondary contours accounted for 83.3%, 50%, 83.3%, 50%, and 50% of the sample, respectively, which is a relatively high proportion.

Because the narrow and long space of medium-scale strip courtyards can easily create a sense of oppression and insecurity, it is necessary to introduce arches and structural elements to increase their spatial layering. Since these courtyards often connect several building entrances, the secondary contour additions that are often arranged at the building entrance and the wall facing the entrance are also more numerous. Among them, elements such as lanterns and couplets are in line with the traditional style and can effectively enhance the courtyard landscape. However, some modern signs have caused interference to the courtyard space due to the confusion in their design [21]. In addition, courtyards with greenery or stone benches accounted for 50% and 33.3% of the courtyard sample, respectively, which is a relatively low proportion, and water features were not found in them. The results show that medium-scale strip courtyards, characterized by strong directionality and spatial dynamism, primarily serve circulation functions; consequently, elements intended for viewing or resting appear less frequently.

Among medium-scale irregular courtyards, those with greenery, water features, or openwork windows accounted for 90%, 40%, and 55% of the sample courtyards, respectively, which is a relatively high proportion. Courtyards with stone tables accounted for 25% of the sample courtyards, which is a relatively low proportion. It can be seen that when designing medium-scale irregular courtyards, the irregular spaces are often arranged in a rich way, with greenery and water features used to mask and remedy the irregular parts of the courtyard, thereby weakening the irregular shape of the space. Furthermore, using the courtyard wall as the “ground” and the openwork window as the “figure”, the openwork window becomes a visual focal point of the courtyard space, which can effectively reduce the feeling of irregularity of the courtyard space under the “spotlight effect” [22]. Simultaneously, in the Huizhou region, where literature and art flourish, these elements possess rich artistic value and scholarly aesthetic, enhancing the spatial level recognition. Stone tables are often

placed in courtyards in conjunction with building entrances to follow or support the building axis. However, in medium-scale irregular courtyards, the alignment with the building axis is weaker, so the placement of stone tables is correspondingly less frequent.

In large-scale complex courtyards, those with water features or stone benches accounted for a relatively high proportion of 40% and 60% of the sample, respectively. These findings suggest that this type of courtyard is generally more open and closely connected to nature, functioning primarily as a space for viewing and rest. The arrangement of more water features, stone benches, and other rest elements enriches the spatial layers and circulation paths of the courtyard. Based on the concepts of “a residence with water possesses spirit” and “accumulating water gathers wealth”, and given that the courtyard is large enough to accommodate water features, these courtyards often incorporate water features to serve purposes such as fire prevention, cooling, and irrigation. At the same time, the leisurely swimming fish in the water express the desire for a free and unrestrained life, roaming between heaven and earth. In addition, courtyards with openwork windows or arches accounted for 20% and 10% of the sample courtyards, respectively, which is a relatively low percentage. The results indicate that these courtyards place greater emphasis on creating a peaceful and comfortable living atmosphere and, due to their private and introverted spatial attributes, rarely establish visual connections with the external environment through arches or openwork windows.

Overall, the analysis reveals that the arrangement of spatial elements varies significantly among courtyard spaces with different morphological characteristics. The arrangement and combination of these elements either enhance the spatial characteristics or mitigate shortcomings. Medium-scale square and irregular courtyards have a high degree of element richness. Among them, medium-scale square courtyards have more elements such as greenery, water features, stone tables, and stone benches. Medium-scale irregular courtyards are mainly characterized by

greenery, water features, and openwork windows. Medium-scale strip courtyards and large-scale complex courtyards have a low degree of element richness. Medium-scale strip courtyards are mainly composed of structures, arches,

plaques, stone tables, and secondary contours, with fewer planar elements. Large-scale complex courtyards are mainly composed of greenery, water features, and stone benches, with fewer vertical elements.

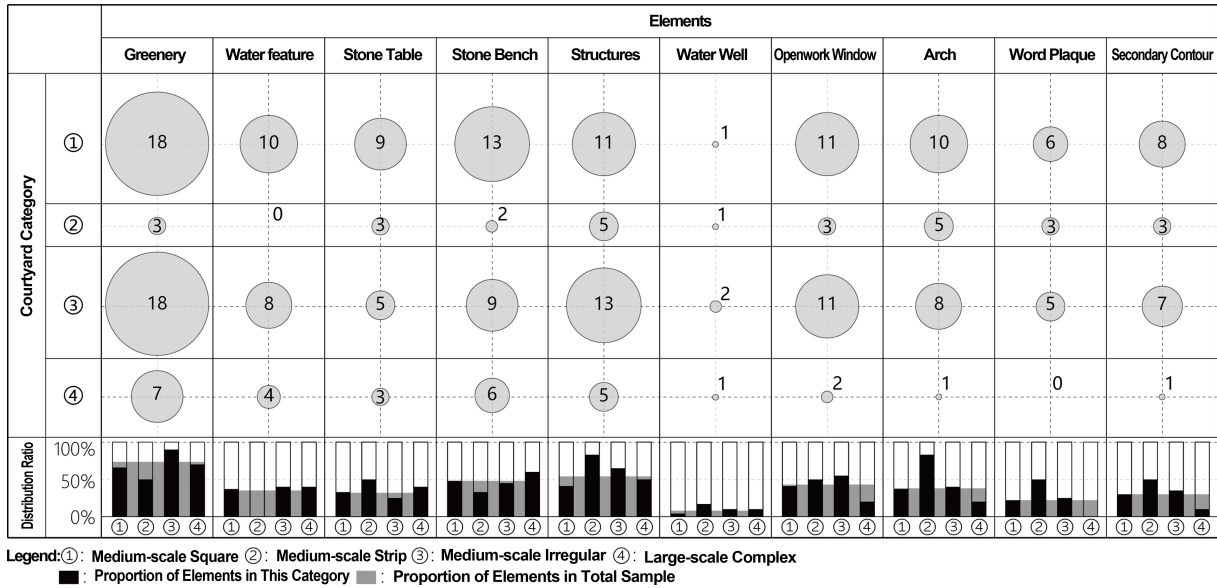


Figure 6 Statistical analysis and comparison of element distribution

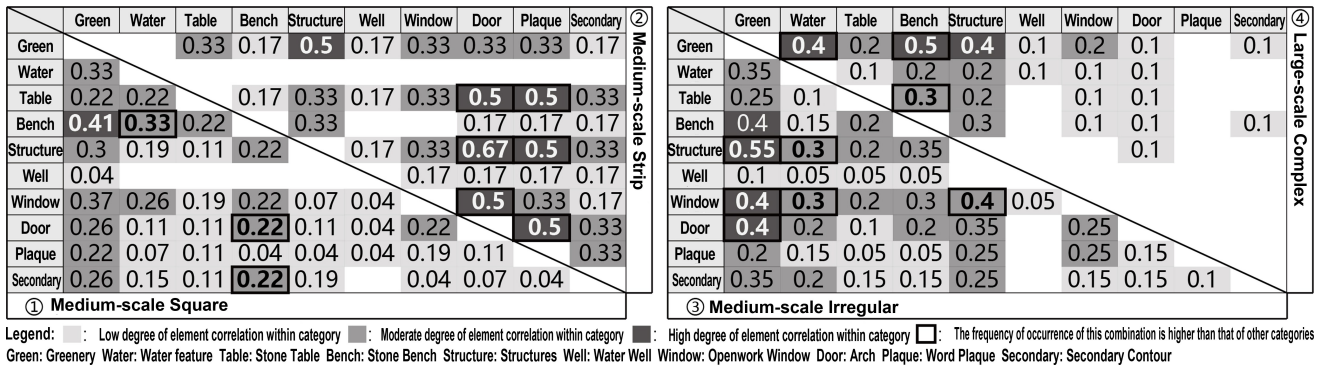


Figure 7 Statistics and comparison of element combinations

3.4 Correlation analysis between elements

The combination patterns of elements in courtyards are complex and exhibit strong individual characteristics. By statistically analyzing the distribution of element combinations in various types of courtyards, the correlation between elements is analyzed (Figure 7), thus providing a reference for the combination of elements in residential courtyards. The proportion of courtyards with various combinations of elements in a given category of courtyards is used as the frequency of occurrence of element combination patterns to express the degree of correlation

between elements in each category of courtyards. If the frequency is below 0.2, the correlation between the elements is considered low; if the frequency is between 0.2 and 0.4, the correlation is considered moderate; and if the frequency is above 0.4, the correlation between the elements is considered high. Overall, the greening elements are highly correlated with elements such as water features, stone benches, structures, or openwork windows, indicating that while introducing natural landscapes, the embellishment of artificial elements is more conducive to creating a spatially permeable, comfortable, and leisurely

courtyard space. Looking at the combination distribution in various types of courtyards, they are mostly arranged around the main constituent elements. The combination patterns are most abundant in medium-scale square courtyards and medium-scale irregular courtyards, followed by medium-scale strip courtyards, while the combination of elements is less abundant in large-scale complex courtyards.

In medium-scale square courtyards, the “greenery-bench” element combination had the highest frequency of 0.41, indicating the highest correlation. Meanwhile, the frequencies of combination patterns such as “water-bench”, “bench-door”, and “bench-contour” are 0.33, 0.22, and 0.22, respectively, which are more frequent than in other types of courtyards, reflecting that the correlation between elements such as water features, arches, secondary contours, and stone benches is relatively higher in this type of courtyard. Combining and arranging these elements can serve to connect the axis, enrich the landscape layers, and optimize the rest space within a relatively small and regular space.

In medium-scale strip courtyards, the common combination patterns are mainly “greenery-structure”, “door-table”, “door-structure”, “door-window”, “plaque-table”, “plaque-structure”, and “plaque-door”, with frequencies of 0.5, 0.5, 0.67, 0.5, 0.5, 0.5, and 0.5, respectively. These patterns appear more frequently than in other types of courtyards, indicating a high degree of correlation between elements such as greenery, plaques, stone tables, openwork windows, arches, and structures. The arrangement of these elements, while increasing spatial layers and reducing the sense of depth, ensures that every section of the courtyard is appropriately sized and exudes an elegant atmosphere.

In medium-scale irregular courtyards, the combination patterns of “green-structure”, “green-window”, “green-door”, “water-structure”, “water-window”, and “structure-window” appear relatively frequently, with frequencies of 0.55, 0.4, 0.4, 0.3, 0.3, and 0.4, respectively. At the same time, these combination patterns are relatively more common in other courtyards, reflecting the high cor-

relation between elements such as greenery, water features, structures, and openwork windows. It can be seen that while individual elements can cover and repair irregular spaces, combining these elements can strengthen the reduction of spatial irregularity, enhance the spatial quality, and transform the courtyard into a highlight of the architectural space.

For large-scale complex courtyards, common combination patterns are mainly “green-water”, “green-bench”, “green-structure”, and “table-bench”. These combination patterns have a combination frequency of 0.4, 0.5, 0.4, and 0.3, which is higher than that of other types of courtyards. In these types of courtyards, elements such as water features and stone benches are often combined with greenery to create a space that feels close to nature, while providing a richer environment for relaxation.

Conclusions

By introducing spatial quantitative indicators to describe the spatial form of courtyards, and summarizing the location characteristics and element distribution patterns of courtyard spatial types based on clustering analysis (Figure 8), the study found that:

(1) Overall, the courtyard area of Huizhou traditional residences is mostly within 100 m². with a suitable spatial scale, which is suitable for construction under the tight land use conditions in Huizhou; the courtyard area is mostly 10% to 40% of the building area, which is in appropriate proportion to the main building and serves as an outdoor supplement to the main building; the aspect ratio can be divided into two categories: between 1 and 2 and greater than 2. The aspect ratios of most of them are between 1 and 2, reflecting traditional design principles emphasizing regularity and stability. Their regular spatial form can give people a comfortable and stable spatial experience. For courtyards with an aspect ratio greater than 2, the space often exhibits a strong sense of dynamism and has more circulation attributes. Regarding the distribution of location, front yards are the most common, followed by backyards, with side yards being the least common. As the

starting point of the architectural sequence, the front yard is often the focus of courtyard design. In terms of element arrangement, greenery elements are the most numerous overall, with structures, water features, openwork windows, and arches also appearing frequently. In terms of element combination, greenery elements are often combined with water features, stone benches, structures, and openwork windows. While introducing natural landscape imagery, this arrangement expresses the ideals of the literati, and the rich elements embellish and enhance the spatial atmosphere that combines the artificial and the natural.

(2) Medium-scale square courtyards are the most common, reflecting that even under the tight land use conditions in Huizhou, there is an enduring priority placed on the creation of courtyard space. The square and stable spatial order is well reflected in the courtyard space, and the form and proportion are consistent with the main body.

These types of courtyards are mostly located in the front yard and back yard. As important circulation organization spaces and extensions of living spaces, the front and back yards require square and comfortable spaces. Therefore, when conditions permit, building medium-scale square courtyards is more conducive to maintaining consistency with the main form and to functional use. In terms of spatial configuration, small and medium-scale square courtyards often combine elements such as stone benches with greenery, water features, arches, and secondary contours to extend spatial functions, enrich landscape layers, and enhance spatial interest. Therefore, when creating courtyard spaces for residential buildings, the primary consideration should be to create a courtyard with a square shape and moderate size, and to embellish and enhance it with spatial elements, thereby forming a comfortable and pleasant courtyard space that extends the building space outdoors.

	Spatial attributes	Ranking of location distribution	Ranking of element edistribution	Design strategies
Medium-scale square	Spatial transition, outdoor supplement	Front>back>side	Green>Bench>Structure=Window>Door=Water>Table>Secondary>Plaque>Well	Maintain the historical landscape pattern of Huizhou traditional residential courtyard spaces
Medium-scale strip	Circulation organization for large residential complexes	Front>side>back	Structure=Door>Green=Table=Window=Plaque=Secondary>Bench>Well>Water	Guide the spatial sequence by creating a sense of directionality in the courtyard, and mitigate the uncomfortable spatial feeling through element arrangement
Medium-scale irregular	Sightseeing, circulation	Side>front>back	Green>Structure>Window>Bench>Water=Door>Secondary>Table>Plaque>Well	Rationally utilize different terrains to create courtyards, and weaken the sense of spatial irregularity through element arrangement
Large-scale complex	Daily living, close to nature	Back>front>side	Green>Bench>Structure>Water>Table>Window>Well=Door=Secondary>Plaque	Construct larger-scale courtyards where conditions permit, to better get close to and dwell in nature

Legend: Green: Greenery Water: Water feature Table: Stone table bench: Stone bench structure: Structures Well: Water well Window: Openwork window Door: Arch Plaque: Word plaque Secondary: Secondary contour

Figure 8 Summary of the regular characteristics of courtyards

(3) Medium-scale strip courtyards are mainly front yards. As the circulation space at the front of the building, the front yard requires convenient circulation access. Because of the spatial dynamism and directionality embodied by the strip courtyard, it is often used as the front yard for circulation organization in larger residential complexes. In terms of element configuration, the main elements are structures and arches, which are combined with greenery, plaques, stone tables, and openwork windows to reduce the sense of oppression and insecurity caused by the narrow space. Therefore, when faced with a long and narrow courtyard space due to land constraints, the sense of constriction can be reduced by using structures, arches, and

other elements to divide and add layers.

(4) Medium-scale irregular courtyards are mainly front yards and side yards. Under the combined effect of irregular land conditions and the regular main building plan, these courtyards present an irregular spatial form. In addition to being arranged as a viewing space, they also undertake certain circulation functions. Because it seeks variation within a regular planar shape, this type becomes a highlight in the architectural space. In terms of element configuration, greenery, water features, openwork windows, and their combinations are the most common elements. The irregularity of the space is reduced by remedying the space and placing a visual center. Therefore, when

faced with restrictions on land use conditions or irregular shapes of residential land, the impression of spatial irregularity can be mitigated by using elements to shield or correct them, or by arranging eye-catching elements to form a visual center.

(5) Large-scale complex courtyards are mainly backyards, which are mostly living and resting spaces. If the land conditions permit, it is more conducive to building a larger courtyard to create a courtyard space that incorporates more landscape and pastoral imagery and is close to nature, so as to foster relaxation and spiritual tranquility in a courtyard environment full of natural charm. In terms of spatial configuration, the layout mainly features natural leisure elements such as water features and stone benches, and often combines them with greenery to provide residents with a comfortable and private living environment. Therefore, where land conditions permit, a large-scale courtyard space can be created by combining natural landscapes and recreational facilities to satisfy the pursuit of living in nature.

In conclusion, by studying the spatial organization patterns of courtyards based on typological analysis, we can understand the general rules of different courtyard spatial arrangements, thus providing a basis for the protection and restoration of Huizhou traditional residential courtyard spaces [23, 24]. Meanwhile, when constructing courtyard spaces for new Huizhou-style residences, attention should be paid to creating regular and square courtyard spaces that provide human-scaled and outdoor spaces that are in harmony with the building's proportions. When land conditions permit, a large-scale courtyard space can be built at the rear of the building, and the natural and private spatial atmosphere can provide a variety of supplements to residential life. The relatively long and narrow courtyard can be used to guide the spatial sequence, and the spatial comfort can be increased by dividing the space through structures and arches. In addition, irregular land use can be used to carry out diversified designs, and spatial elements can be inserted to remedy defects or form a visual center to soften the impression of irregular space [25, 26].

Sources of Figures and Tables

All figures and tables in this article were drawn and photographed by the authors.

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