QUANTIFICATION AND TYPOLOGY METHODS FOR SPATIAL REGIONALISM

From Traditional Residence to Modern Chinese-style House Design

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Abstract. The cognition of Regionalism in architecture has transferred from the surface to the essence, from the building appearance to space. Modern Chinese-style houses have sprung up all over the country these years but always fail to find back the main characteristic of space in traditional residences. Therefore, the paper focuses on the question of "what are the main features of the space in traditional Chinese residence", proposing 5 spatial quantification indexes for residential space and a score evaluation method to measure Chinese-style matching degree (Mch) with the help of a modified graph map generation method. 10 traditional Chinese houses and 16 built-up modern Chinese-style houses are taken as samples for empirical research. The paper also puts forward a hypothesis testing model for architects, which can quickly check the Chinese-style matching degree of the scheme and strongly support the design process.

Keywords. Spatial regionalism; spatial quantification; Chinese-style matching degree; typology; traditional Chinese residence.

1. Introduction

The regional uniqueness is the pursuit of all cultures and the field in them, including architecture. At the beginning of the 21st century, various modern Chinese-style houses sprang up all over the country and are vigorously pursued by the Chinese real estate market. However, few discussions were aroused in the academic field, leading to a lack of theory and methodology in Chinese-style house design. Also, most of the existing modern Chinese houses focus mainly on copying the details including the windows, the facade and the decoration to imitate the image of traditional residence but the most symbolic, changeable and fascinating part: the space pattern was ignored. The evaluation of the design mostly stays in the qualitative description, but the quantitative methods are very few.

Space is difficult to be understood and perceived. Fortunately, some studies have provided the potential to explain and quantify it. Many scholars have made

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attempts to associate graph theory with the architecture field. Levin (1964) first applied the graph theory to the architecture plan. Cousin (1970) and Friedman (1975) have tried to apply graph theory to design. March and Steadman(1971) gave a systematic description of applying the graph theory into architecture thinking, emphasizing the structural relationship of space rather than focus on the properties like area or volume. Space syntax (Hillier and Hanson,1984) is a milestone, which links the space morphology to the social and cultural aspects: space can reflect the process of social change and also affect the social change. Space syntax has been widely used in the interior space of the housing since it was proposed. Hanson (1998) transformed the floor plans into the 'justified map' and tested the relationship between the space form and the social changes based on a traditional housing of the Banbury region of Oxfordshire in the Renaissance. Brown (1986) analyzed the form of the dwelling in the seventeenth century in London through the justified map and Blanton (1994) illuminated the links of the lifestyles and the form of house plan.

There are two types of maps that are used to describe the structure of space. One is the access graph (called the Morphology map below) which erases the physical attributes but still retains the location information of the internal units. The other is the 'Justified form of access graph' (called Justified map below). All properties of the space are ignored and only the adjacency relations are preserved. However both of them have weaknesses: when the relative positions of space move, countless fractals will generate in the Morphology map. And the missing form and dimension in the Justified map will cause it to be out of touch with the architectural design.

The paper first proposes a modified Morphology map and a Justified map automatic generation method. Secondly, 5 spatial quantification indexes are constructed to unravel the main features of the space in Chinese-style residences based on the empirical research of 26 residential samples. Thirdly, a score evaluation system of a Chinese-style matching degree is put forward. Finally, 4 'genotypes' in Chinese residence and a hypothesis testing model is presented through a case study, which can strongly support the design process and lead to a scheme with spatial features of Chinese-style residences.

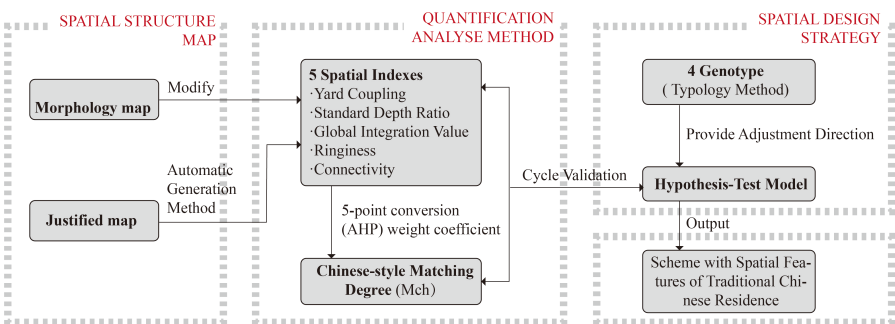


Figure 1. the study flow.

2. Principles and Adjustments of Space Topology Based on Space Syntax

2.1. MODIFIED MORPHOLOGY MAP

In the typical process of drawing a Morphology map, the circles representing rooms are usually placed at the geometric center of the space unit. But the defects are: the map is irregular and the relative positions between the units are unevenly distributed. Therefore, some adjustments have been made:

- Step1: Move the circles of the unit close to the outer contour to the outer contour, and move the circles of the unit at the corner directly to the corner point, and move the circles at the middle unit to their physical centers.
- Step2: Set a two-dimensional space grid, take the four corner points (Ba, Se, Yf, L) and the center point C as the reference points, and move the remaining points evenly on the Moore neighborhood of the reference point following the adjacent positions. When the Moore neighborhood can't meet the requirements, add the secondary level grid.

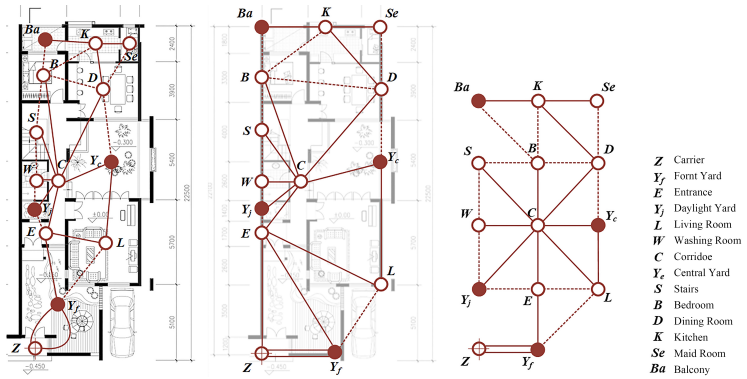


Figure 2. Example of modified morphology map(the Fifth Garden in Shenzhen).

2.2. JUSTIFIED MAP AUTOMATIC GENERATION METHOD

With the increase in the number of rooms and the complexity of the space structure, it will become more and more difficult to manually identify the correct number of steps for each unit. Take a traditional residential house in Jinyun, Zhejiang Province as an example. The house has 5 entrances. Starting from the outside, five different ways can lead to the same internal space with different steps and depth. It takes a long time and brings obstacles to researchers when measuring the number of steps of multipath paths. To overcome the shortcomings of traditional manual methods, the paper proposes a Justified map automatic generation method based on adjacency matrix and network analysis tool processing.

First, enter the connection relationship between each space in the adjacency matrix, if space is connected, the value is 1, and the rest is 0. Then, use *pajek* module in the social network analysis tool *ucinet* to quickly visualize the complex network.

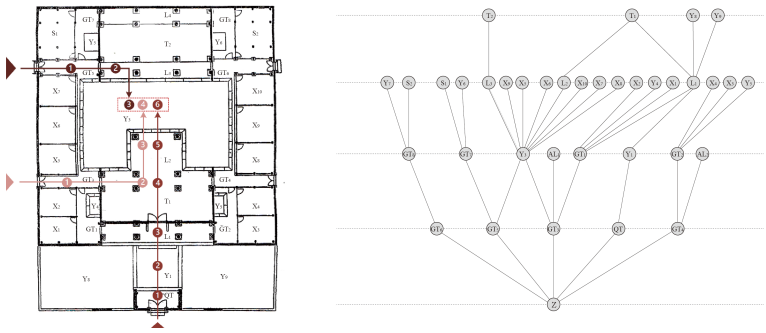


Figure 3. (left)the plan of house in Jinyun, Zhejiang (right) automatic generated justified map.

3. Spatial quantification indexes construction and calculation method

Chinese traditional houses present a modular paradigm with 'Jian' (a quantifier to measure the size of a building). The external interface of the Chinese house is extremely closed, but the interior next to the courtyard is often translucent and open.

In ancient times, cohabitation of three generations (over 15 people) was the most basic family structure. The area of the houses and the number of rooms were always very large. Nowadays, the family structure has changed a lot, and most of them are core families (3-4 people), so the number of rooms in Chinese-style houses is reduced. Therefore, we hope that in the study of quantification algorithms, differences brought by the number of rooms and the size of the building can be eliminated. Five indexes are chosen to measure the spatial features. Among them, standard depth ration, global integration value and connectivity are indexs that have been widly known and used. Yard coupling and ringiness are first proposed in this paper for describing the typical features in Chinese traditional dwelling.

3.1. SPATIAL QUANTIFICATION INDEXES

- **YARD COUPLING** (Y_c^1) The yard is the most significant spatial feature of traditional Chinese houses. The first index is used to measure the interaction between the courtyard and the indoor space.Where s is the number of solid lines in the modified Morphology map (connecting) between indoor units and courtyard, r is the number of dash line (adjacent but unreachable), k is the number of indoor units adjacent to the courtyard but without windows and v is an indoor unit that is not directly adjacent to the courtyard unit but can see the courtyard through the window. S is the total number of solid lines in the modified Morphology map. The larger the value of the result, the closer the communication between internal indoor and external courtyard spaces. Finally, a square arcsine transformation is performed on the result to improve the normality of the distribution.

$$Y_c^1 = \arcsin\left(\sqrt{Y_c}\right) = \arcsin\left(\sqrt{\frac{s + 0.25v - 0.5r + 0.5k}{S}}\right) \quad (1)$$

- **STANDARD DEPTH RATION** (S^1) Carrier depth is used to characterize the sequencing of a space. To compare systems of different scales, take twice the ratio of MD_Z to MD_{max} plus MD_{min} and record it as the standard depth ratio, and do the square arcsine transformation as well.Where MD_Z is the carrier mean depth, MD_{max} and MD_{min} are the maximum and the minimum of the carrier mean depth.

$$S^1 = acr\sin\left(\sqrt{\frac{2MD_Z}{MD_{\text{max}} + MD_{\text{min}}}}\right) \quad (2)$$

- **GLOBAL INTEGRATION VALUE** (INT) Integration is the degree of aggregation or dispersion between a certain element and other elements in a space system, which measures the accessibility of the space system.
- **RINGINESS** (R^1)The Ringiness corresponds to the wandering feelings in traditional Chinese gardens and residential design. To simplify the calculation, only the fundamental circle will be calculated. Where *n* is the number of the space unit and *I* is the number of the fundamental circles. Similarly, make a square arcsine transformation. The greater the value, the stronger the wandering feeling of the space, the richer spatial levels, and the bigger the space feels.

$$R^1 = \arcsin\left(\sqrt{R}\right) = \arcsin\left(\sqrt{\frac{I}{2n-5}}\right) \quad (3)$$

- **CONNECTIVITY** (C)Connectivity is used to quantify the organizational effectiveness of traffic space, including corridors, aisles, halls, stairwells. The value is the average integration of traffic space divided by the global integration of the whole system.

3.2. SELECTION OF TYPICAL SAMPLES AND CALCULATION OF INDEX

According to the five indexes constructed above, 10 well-known traditional houses, most of which are cultural heritages, and 16 built- up and widely reported and studied modern Chinese houses are selected as samples. The paper takes the traditional houses in Jiangsu and Zhejiang provinces as the research content of the traditional houses as they are the most typical ones and are less influenced by the foreign culture. The case selection strives to cover different scale types and periods. In this paper, two cases (one traditional, one modern) are presented in detail.

Jiujian House is designed by famous Chinese architect Zhang Yonghe, located in Pudong New District, Shanghai. The room design reproduces the Chinese architectural tradition and architectural intentions of “deep courtyard”. Each villa

occupies an area of 3 acres, surrounded by 3.5-meter high walls, which effectively guarantees the privacy of the owner.

Table 1. The information of Jiujian House and Gezhai.

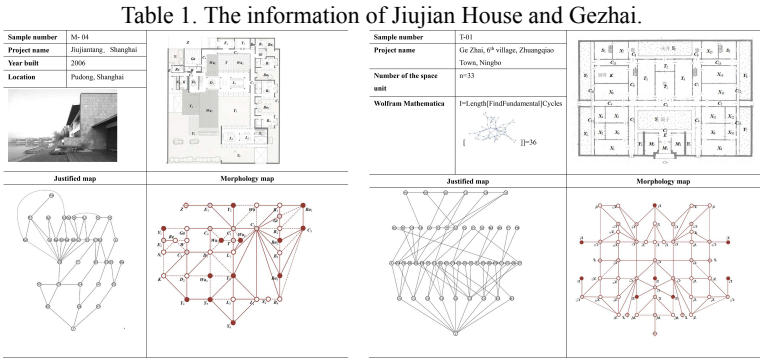


Table 2. Fundamental index and spatial features of 26 samples.

Number	Project name	Fundamental index							Spatial feature				
		s	r	k	S	v	n	l	Y_C^1	R^1	S^1	INT	C
M-01	Yunjian Water Village	3	3	0	18	2	15	3	0.7297	0.3537	0.5515	1.1612	1.512.8
M-02	The Lushi Hill	4	7	2	19	6	17	2	0.7061	0.2657	0.5967	1.0320	1.4307
M-03a	Shenzhen 5th Garden	5	4	0	13	2	14	1	0.8626	0.2102	0.7758	1.0320	2.3975
M-03b	Shenzhen 5th Garden	3	4	2	11	0	14	0	0.6473	0.0000	0.8529	0.7329	1.6867
M-04	Jiujiantang，Shanghai	18	19	3	52	2	35	20	0.7950	0.5880	0.5434	1.0535	1.2390
M-05	Shanghai 5th Garden	2	4	2	9	1	11	1	0.6447	0.4086	0.8440	1.0716	2.4772
M-06a	Jinyu Huafu	4	2	0	14	1	12	3	0.6591	0.2315	0.8440	1.0122	1.3607
M-06b	Jinyu Huafu	5	4	0	14	1	15	1	0.8033	0.2014	0.7717	1.0502	1.4689
M-07	Jiujiantang，Nanjing	8	5	2	33	2	24	8	0.5829	0.4460	0.5944	1.0723	1.4481
M-08	Peach Blossom House, Suzhou	4	3	0	24	6	18	6	0.5236	0.4555	0.6960	1.2137	1.4490
M-09a	Taoli Chunfeng Villa	9	6	2	23	0	18	7	0.7637	0.4952	0.7353	1.0032	1.0926
M-09b	Taoli Chunfeng Villa	8	5	1	16	2	14	2	0.9443	0.2993	0.8428	0.6787	1.8257
M-09c	Taoli Chunfeng Villa	6	9	1	17	0	17	1	0.8741	0.1868	0.8428	0.7312	1.4393
M-09d	Taoli Chunfeng Villa	9	1	1	18	0	15	4	0.7854	0.4115	0.7391	0.9072	1.0631
M-10	Peach Blossom House, Linqi	5	5	0	14	2	14	2	0.8571	0.2993	0.7276	1.0259	1.3314
M-11	Peach Blossom House, Yunxi	5	4	0	19	1	18	2	0.6658	0.2568	0.6050	1.2177	1.5446
M-12	Taoyuan Town	8	6	1	19	1	19	3	0.8514	0.3063	0.5779	0.7072	1.1848
M-13	Phoenix Mansion	3	3	1	14	1	15	2	0.5835	0.2868	0.7324	0.9782	1.4433
M-14a	Dongziguan Affordable Housing for Relocalized Farmers	4	2	0	17	4	16	3	0.6361	0.3398	0.6998	1.1796	1.4689
M-14b	Affordable Housing for Relocalized Farmers	4	4	0	17	2	14	5	0.6666	0.4850	0.6290	1.1378	1.6628
M-15a	Yunlin Chunfeng House	5	2	0	20	2	18	4	0.6066	0.3674	0.7677	0.8847	1.1351
M-15b	Yunlin Chunfeng House	3	2	0	11	2	11	2	0.6940	0.3501	0.7777	1.0675	0.8879
M-15c	Yunlin Chunfeng House	3	3	2	15	2	12	4	0.5426	0.4767	0.8331	1.0373	1.2522
M-16	Fengqiao Image House	3	3	1	14	2	13	2	0.6028	0.3137	0.6155	1.2401	1.4926
T-01	Ge Zhai, 6th village, Zhuangqiao Town, Ningbo	21	8	2	84	22	33	36	0.6343	0.8761	0.4433	1.2408	1.2192
T-02	Wuben House, Baitai Town, Dongyang	5	2	2	20	11	20	9	0.6719	0.5318	0.4152	1.5292	1.7479
T-03	Chen Zhai, 8th Village, Tiantai Town	5	1	1	23	7	18	11	0.5725	0.6381	0.4710	1.2198	1.2293
T-04	Mo's Manor	38	14	4	82	5	58	31	0.8251	0.5568	0.3342	1.1880	1.2270
T-05	A House in Feijia village, Yuyao Town	12	12	5	67	27	48	23	0.6142	0.5268	0.3391	1.1193	1.2277
T-06	Shuangmei House, Xinye Village	9	5	1	27	0	22	9	0.6923	0.5011	0.5551	1.1041	1.2102
T-07	Yetong House, Xinye Village	8	0	0	22	3	20	5	0.6824	0.3876	0.5207	0.9653	1.1953
T-08	Han Zhai, Dongbei Street	45	35	11	139	3	121	29	0.7005	0.3574	0.3119	0.8424	1.2608
T-09	Liu Zhai, Liaojia Lane	23	24	9	56	0	50	17	0.8301	0.4368	0.3563	0.9654	1.1350
T-10	Zhang Zhai, Songxianzhou Lane	26	17	8	58	4	56	8	0.8286	0.2770	0.4364	0.6750	1.0870

Gezhai is a typical Chinese traditional residence, located in Dongyang, Zhejiang Province. It is a typical "Thirteen Jian" style, consisting of three main rooms and five wing rooms on left and right with three courtyard inside the house.

Tabel 2 shows the fundamental indexes and spatial quantification indexes of all samples.

4. Score evaluation system of Chinese-style matching degree

To comprehensively evaluate the spatial matching degree between modern Chinese houses and traditional ones, a standardized evaluation system is established based on the five spatial indexes. For the convenience of measurement, the five-point evaluation method is adopted to map the original value. The rules are as follows: for each index, the valley value and the peak value respectively correspond to 0 points and 5 points. All the values in the middle are scored by the linear transformation, and those below the valley and above the peak are still scored 0 or 5 points.(Table 3)

The objective function: Chinese-style matching degree (Mch) is then defined to characterize the degree of matching between modern Chinese houses and traditional houses in spatial typology.

$$M_{ch} = w_1 \cdot G_Y + w_2 \cdot G_R + w_3 \cdot G_I + w_4 \cdot G_S + w_5 \cdot G_C \tag{4}$$

Where G_Y, G_R, G_I, G_S, G_C respectively represent the value of Yard coupling, Ringiness, Global integration, Standard depth ration and Connectivity after 5-points conversion and w_1, w_2, w_3, w_4, $w_5$are the weight coefficient corresponding to each factor. This paper uses the analytic hierarchy process (AHP) to calculate the weight coefficient with the help of the evaluation assistant software *yaahp*. Since the Chinese-style matching degree only involves one middle layer, it is relatively simple to operate. w_1, w_2, w_3, w_4, w_5 are respectively 0.3955, 0.2398, 0.0679, 0.1152, 0.1816.

Based on the evaluation criteria above, the five spatial quantification indexes in the 26 samples are calculated into corresponding scores and Mch are calculated. The results show that the average (2.37) and median (2.36) of Mch in all test samples are very close to half of the full score (5.0) and about 71% are between 2.0 and 3.0. In the meantime, the data distribution is roughly symmetrical, and the skewness is not obvious, which proves that Mch is statistically significant.

It is worth noting that Mch is a score evaluation system for modern Chinese houses. Traditional houses are used mainly as a reference to find the functional characteristics of traditional houses.

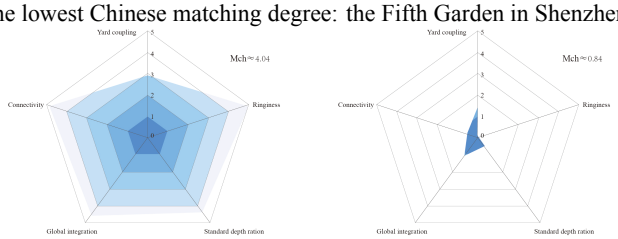
Table 3. 5-points conversion .

	yard coupling		**ringiness**		**global integration value**		**standard depth ration**		**connectivity**	
	valley value	peak value	valley value	peak value	valley value	peak value	valley value	peak value	valley value	peak value
Original value	0.5	1	0.1	0.6	0.6	1.1	0.5	0.9	0.8(left) 1.8(right)	1.25
Score	0	5	0	5	0	5	0	5	0	5

By comparing the scoring patterns of cases, we can explore some spatial strategies. The cases M-03b, M-05, and M-13 have low Mch (less than 2.0). In

M-03b, space is closed, and the entire space is organized in series without any interaction. Although M-05 has a central courtyard, no windows are opened on the walls beside the yard that faces the kitchen and the living room, which creates a barrier. M-13 is a typical three-part division of "yard-house-yard", and the middle part is long and deep with obvious internal and external separation.

Table 4. (left)the radar charts of the highest Chinese matching degree: Jiujian House and(right) the lowest Chinese matching degree: the Fifth Garden in Shenzhen.



5. The spatial strategy and optimization strategy of the Chinese residence

5.1. IDEAS AND TECHNIQUES OF CHINESE STYLE HOUSE DESIGN DRIVEN BY "GENOTYPE" SPACE

Using the method of spatial typology, by comparing the spatial features and the scores of Mch of each case, four key features of Chinese residence are identified and extracted which can be called "Genotype".

The first one is the **Central Courtyard**. The centrality of the courtyard of the Chinese-style house is the most important feature that distinguishes it from the townhouses in Europe and America. In the Chinese-style house, various courtyards are located in the center or in series on the central axis and the internal rooms are closely connected with it. The second is **Corridor Space**. In traditional Chinese houses, the corridor space is divided into corridors surrounding the courtyard and corridors connecting most of the rooms which are closely intertwined. The third is the **Migratory of space**. Traditional Chinese Houses provide people with good experience of wandering feelings of multiple open spaces, multiple functions and strong circulation which is not a single perspective, but a multi-dimensional connection and penetration. The last one is the **Entrance space**. The treatment of the entrance space in traditional Chinese houses is delicate. Usually, a certain sequence is realized by alternate conversion of the front yard, gate, corridor, and central courtyard. It appears to be closed first and then widened or vice versa, which is interesting and contrasting.

5.2. SPACE DESIGN PROCESS SUPPORTED BY BOTH SPACE TYPE AND MEASUREMENT

The process of design is relatively complicated, and it doesn't have a unique solution like logical reasoning. The design process is like a "**black box**" that is subjective but hard to explain. What we can know is only the input and output information, but it is difficult to analyze the design process. Architectural

design is a cyclical and constantly revised process, which can be regarded as a ”hypothesis-test” cycle. Based on the Chinese-style matching evaluation system, the ”hypothesis-test” model can quickly verify whether the plan has the spatial features of Chinese-style traditional houses.

Architects first collect, analyze and sort out the external constraints in a certain project, predicting the effects of influencing factors and formulating corresponding strategies. Secondly, use the method of spatial typology, analyze the traditional residential houses in the local area, and summarize several representative spatial types. Then import external constraints and internal concepts to the black box and output the preliminary scheme. Through the Chinese-style matching degree evaluation system, architects can quickly test its spatial Chinese-style features and make adjustments according to each index. Through multiple rounds of the hypothesis-testing process, the best solution will finally be selected.

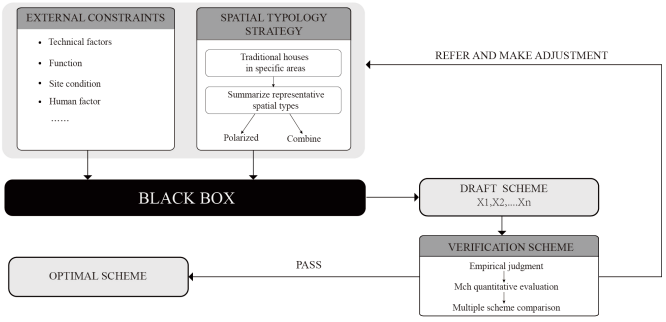


Figure 4. hypothesis testing design-process model.

5.3. EXAMPLE VERIFICATION

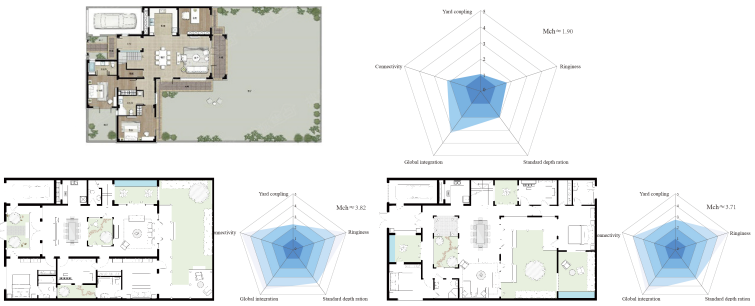


Figure 5. Jiangnan Li project and two modified versions.

Take the Jiangnan Li project, for example. First, test its Chinese-style matching degree, then adjust and optimize the space typology to increase the Chinese characteristics of the space. It’s a low-rise courtyard villa group, which is a typical

modern Chinese house in recent years. The indoor space of it is intensive and compact with a large backyard. Mch is only 1.91. The courtyard coupling is the biggest shortcoming of the scheme, which is only 1.1, followed by ringiness and standard depth ratio of less than 2.0. Therefore, the direction of adjustments is to increase the interaction between the courtyard and the interior space, reduce the number of steps the indoor space takes to the entrance and increase the wandering feeling. Also, a mixture of different types of "Genotype" is adopted to adjust the plan. Each index and Chinese-style matching degree in the two adjusted schemes have been significantly improved and are at a high level in the overall samples.

6. Discussion

This paper starts from the graph theory and proposes a modified way of drawing the graph map. With the modified morphology map and the automatic generation method, it's easier to get an accurate map to represent the spatial relationship between each other. Also, the space features in Chinese residential houses are quantified by 5 spatial indexes and the Chinese-style matching(Mch) degree can be measured in a fast and direct way through the objective function, which will transform the design process into a more operable stage by the hypothesis-testing model. Also, the summary of the "Genotype" will provide clear adjustment directions.

However, there still have shortcomings. The "Hypothesis-test" model can only test whether the scheme has the spatial feature in traditional Chinese residences, but can't precisely control every step in the design process, which still relies a lot on the subjective initiative of architects.

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