UDC 711

PENG Dandan, QINQin, HU Youpei
School of Architecture and Urban Planning, Nanjing University,
China, Jiangsu, Nanjing, 200093
e-mail: youpei.hu@nju.edu.cn

A STATISTICAL RESEARCH ON THE TYPICAL PATTERNS OF MODERN HOUSING FABRICS, CASE STUDY OF NANJING, CHINA

Abstract: *After nearly 20 years of massive social housing construction and another 20 years of housing real estate development, Chinese cities basically solved the citizen's housing problem in the second decade of the 21st century. As a consequence, the major physical component of contemporary cities is modern housing fabrics, which cover over 30% urban land. It is generally believed this magnitude housing development is dominated by modernism residential building with a standard image of a slab apartment. However, as revealed in this research, the real situation is far more diversified and complicated, with various building types, like villas, slabs, towers, and different spatial arrangements, like parallel, zigzag, enclosure. How to classify these diversified realities and what are the typical patterns of different housing fabrics? To answer these questions, this research collected more than 200 housing fabric samples across the city of Nanjing. The latter is the Capital of Jiangsu Province, and a typical modern mega-city in Yangzi River Delta area. To get the reasonable categories of fabric types, a comprehensive classification system is applied. Different from the too simplified classification based on single parameter, building height, adopted in the national housing standard, this classification system is based on the matrix of various parameters, including building height, arrangement, and a building type. The various parameters and their intricate combinations guarantee the classification to be capable to seize and distinguish the formal features of different fabrics. Spacemate, a charting tool developed by B.M. Pont and et al. in TU Delft, is used to testify the classification. After the classification, the samples are divided into 21 categories. For each category, data samples, like spacing, dimension of building footprint, height, density, land coverage, and et al. are collected and a statistical analysis are conducted. Based on this qualitative sample studies, the typical patterns and their statistical models are built up. In the application part, a bioclimatic performance study of these typical patterns is presented. Due to the typicality and statistical precision, the complicated co-relation between urban fabric and bioclimatic performance could be discovered, efficiently and convincingly.*
Keywords: *urban fabrics, modern housing type, statistical analysis.*

Introduction

Chinese cities faced a serious housing shortage after the 70s of the last century because of a huge population and rapid urbanization. In the recent 40 years, through massive urban renewal and by virtue of a rapid growth in real estate development, Chinese cities have basically solved the citizen's housing problem in the second decade of the 21st century. As a consequence, the major physical component of contemporary cities is modern housing fabrics that covers over 30% of urban land. They form the base of urban morphology. These new residential buildings are usually modern apartment buildings, creating a homogeneous impression of modernism's slabs. However, as revealed in this research, the real situation is far more diversified and complicated, with various building types, like villas, slabs, towers and different spatial arrangements, like parallel, zigzag, enclosure.

How can we describe these diversified housing fabrics accurately? Namely, how can we classify appropriately and describeprecisely the formal features of housing fabrics. A further and latent question is how the modern housing fabrics form the base of a city.

In the classical urban morphology theory, urban fabrics are usually analyzed from three levels, namely a street block, a plot and a building (Conzen, 1969). Thistriple-layer structure perfectly fits the compositional logics of western cities. However, when it is applied to the subject in this paper, we face problems. As shown in Figure1, it is a typical section of the inner city of Nanjing, which is the case study city of this paper. First, the street blocks in the section, just like other Chinese cities, are diversified in sizes and shapes. Second, residential plots are greatly different in scale and form. This is caused by complicated changes in land ownership and ever-changing space production systems. The irregularity and disorder of street blocks and plots result in difficulties todefine the standard types of street blocks and plots. It is difficult for us to describe and explain the housing fabric of the modern Chinese cities with the "building-plot-street block" compositional logic. The topic of this paper, that is the morphological description of the Chinese modern housing fabric, seems to be simple, but actually is difficult for the lack of theory.

In this paper, a key concept is put forward: a fabric pattern, which is a fabric segment, formed by several individual buildings according to the fixed spatial arrangementrules. This segment can be infinitely duplicated in all directions to fill in large urban area. With this concept, the above mentioned controversiality in the plot and street block level of theurban form are suspended, andthe influences of the fabric patterns on urban morphology are highlighted.

Figure 1. A typical section of the inner City of Nanjing

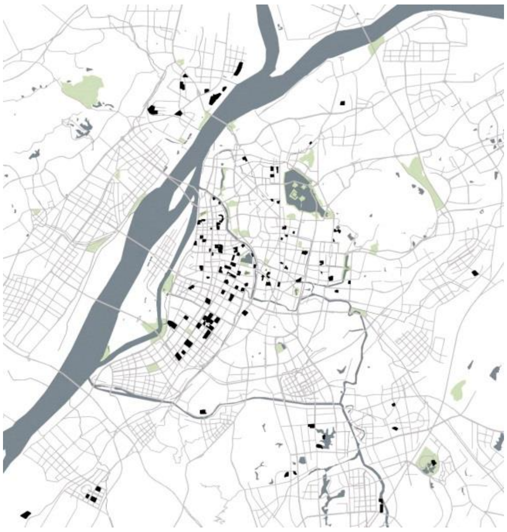


Figure 2. 114 residential community samples in the City of Nanjing

Nanjing is selected as the case study city. It is the capital of Jiangsu Province and a typical modern mega-city in the Yangtze River Delta area. It can be a representative in the Yangtze River Delta region, and to a certain degree, a representative of a modern Chinese city.

What needs to be noted is that modern Chinese houses, though roughly obey the same arrangement logic, are sensitive to geographic positions due to the restrict regulation of sun access. As a consequence, housing fabrics in different regions of China have certain difference. The differences mostly liein the variations of geometric values in the same patterns, for example, in the difference of a width to height ratio between front and rear houses. Therefore, one the one hand, the housing patterns put forward in this paper are to be applicable to more regions in China in configurational level. On the other hand, the formal feature values of each pattern need to be adjusted in case of specific cities.

114 residential community samples (Fig.2) are selected from the main city of Nanjing. The samples are classified into several fabric patterns according to the synthetic classification framework proposed in this paper. Then, the geometric parameters of each patterns are

statistically analyzed from the sample groups, thus quantitatively defining the housing fabric patterns could be done. Gross fabric index parameters (a plot ratio, coverage rate and mean height) are used as examination standards to verify the correctness of the fabric patterns, and Spacemate tool is adopted as the verifying platform.

Classification of patterns

Generally, Chinese urban houses are classified in two ways. The first way is the building height. According to heights, buildings are classified into low-rise buildings, multi-story buildings, small high rise buildings, medium high buildingsand high rise buildings with a height of less than 100m. The purpose of the classification is to distinguish the buildings by height to match different fireproof standards. This classification is regulatory, selected from the official building codes (GB50352,2005; GB50096,2011; GB50016,2014) However, it fails to distinguish the spatial arrangements of the fabricsprecisely. The second way is found in the standard residential area planning text book and handbook, andapplied to the daily design practice (Deng and Wang,1996; Zhu and et al.,2011; Hu,2006; Huang and Zhu,2016). It classifies housing fabrics by several typical arrangement patterns, such as a parallel slab type, a dot type, an enclosure type and etc. This classification seems to work more effectively in the significant classification of the housing fabrics. However, this classificationis relatively vague, rough and insensitive to building heights. It does not meet our requirements for an accurate description.

The classification framework adopted in this paper is based on the building height and arrangement pattern synthetically. Namely, it is a two-dimensional matrix that integrates the building height and arrangement pattern.

1. The dimension of a building height: Following the official building codes, residential buildings are classified into the following 5 categories:

1) Low-rise buildings (F3): buildings with three or fewer stories, mainly detached villas or town houses. Due to high prices, there are the minority in the urban housing family.

2) Multi-story buildings (F6): buildings with a story number within a range of 4 to 7 (sometimes up to 8). This type of buildings usually has 6stories.In accordance with the buildingcodes, an elevator is required for buildings with over 6 stories. As a consequence of this regulation, we can see that the majority of urban housing is 6-story buildings. However, in reality, we will find some special situations that do not obey the regulation absolutely. One situation is that the dwelling unit on the 6th floor is a double-floor unit. In this case, elevator is not a necessity even if the total number of stories reaches 7. In another case, the strict building codes have been issued after the construction of some old residential communities, so that these buildings may also have 7 or 8 stories. For these special cases, we will tag them as multi-story buildings, because they still obey the architectural logic of a typical multi-story building.

3) Small high-rise buildings (F11): buildings with a story number within a range of 8 to12. The majority of the small high-rise buildings have 11 stories because two elevators and a smoke proof staircase are required for buildings with over 11 stories in accordance with building codes. The buildings with 12 floors that have double-floor housing units on 11th floor, still belong to this type.

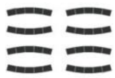
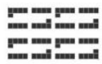
4) Medium high-rise buildings (F18): buildings with a story number within a range of 12 to 19. The majority of the medium-and high-rise buildings have18 floors because two safety exits and smokeproof staircases are required for buildings over 18 stories in accordance with building codes. Like the previous types, buildings with 19 floors that have a double-floor housing unit on 18th floor, still belong to this type.

5) High-rise buildings (F29): with more than 18 floors but a height of less than 100m. Buildings with this height are diversified in a story number, usually having 26, 30 and 33 stories. These types of buildings have a maximum of 33 stories because buildings over 100m are super-high-rise buildings according tothe building codes, and their design and construction standards are greatly higher than those of the common high-rise buildings. At present, there are only a few super-high-rise residential buildings in China.

2. The dimension of spatial arrangement pattern: we put forward 8 arrangement patterns according to the severalstandard residential area planning texts book and handbooks mentioned above. The patterns follow the compositional sequence of a dwelling unit -apartment unit-residential building-building group, from the small-scale to the large-scale. Dwelling units are assembled around a vertical circulation core (a staircase, an elevator well) to form anapartment unit, whichusually includes 2-4 dwelling units (for some high-rise buildings, up to 8-10 houses) on each floor. The apartment unit is a standard module to form a residential building. The latter assembles the apartment units in various ways, for example, a slab, a dot, azig-zag and curved line ways. At last, one or several (usually 2) limited types of residentialbuildings are arranged to form a fixed building group according to certain space interval rules. Thesearrangementsinclude aparallel-slab pattern, adot-array pattern, aslab-dot-mixed pattern, an enclosure pattern and etc. Generally speaking, diversified arrangement patternsare mainly formed by assembling of buildings and apartment units, instead of dwelling units.

Table 1

The 18 typical patternsof modetn hosing fabric in Nanjing

	S1	S2	S3	S4	S5	ST1	T1	T2
F3								
F6								
F11								
F18								
F29								

Based on the above-mentioned two dimensions, a total of 5×8 patterns can be obtained(Table.1). This classification framework is applied to the 114 collected samples, which means that the samples are classified according to the classification standards. It is found that not all the categories in the classification framework have corresponding samples in reality. For example, the high-rise enclosure pattern (S5-F29) is not adopted in real projects and only theoretically exits because of its low efficiency in land developing, and poor architectural quality. After excluding merely theoretical patterns, we found a total of 18 patterns existing in reality. It can be seen that, the most patterns are found from the multi-story buildings, and as the height rises, patterns become fewer.

Statistical analysis and qualification of the patterns

The patterns given in the above section arepresented in a diagram form. In each pattern, specific geometric parameters (such as the spacing between buildings, the length and height of a building) are not defined. The geometric parameters of the samples of the same pattern are collected, and statistically analyzed to build the standard quantitative model of the pattern.

The most popular multi-story parallel slab pattern (S1-F6) is taken as an example(Fig.3). To quantitatively describe the form of the pattern, the values of the following geometric parameters need to be known: the length and width L/W of each apartment unit, the number of units (n) and stories (H, the height between every two stories of a building is usually 3m) of a single building, north-south spacing and east-west spacing (Y/X) between single buildings. Therefore, a total of 6 geometric parameters (L,W,n,H,X,Y) are needed to define the pattern. The seven samples belonging to the pattern are measured with the 6 geometric parameters. It has been found that , the statistical values are in a normal distribution form, which means that the arithmetic mean values can be used as the standard statistical values of the parameters.Besides these 6 geometric parameters, a rotation of pattern is observed in each sample. However, in most cases, the rotation is caused by the aligning to the boundary of a plot or a street block. The rotation angle is not an edogenous parameter, and is excluded from the geometric parameters of the pattern. With the 6 geometric parameters, the statistically quantitative model of the pattern is defined accurately.

A multi-story point-slabpattern (ST1-F6) is taken as another example(Fig.4). Compared to the parallel slab pattern, it has a more complicated form and needs to be defined with more geometric parameters. A total of 8 parameters are used, including the length and width of the point unit, the length and width of the slab unit, the number of the slab units, the average height, and the spacing in two orientations. The statistical values of the 8 parameters are obtained through the sample analysis and statistical study, and the quantitatively standard model of this fabric is defined. Comparing the standard model to the real samples, it can be found that the model is more regular than the samples. However, the difference does not deny the validity of the model; on the contrary, we believe that the significance of the model lies in its simplicity and standardization. In real cases, irregular transforming happens on the local scale, due to the impact of the local context, but it did not essentially change the arrangement logic of the fabric. The purpose of the standard model is to remove the local irregularity and to present the fabric itself in a classical form.

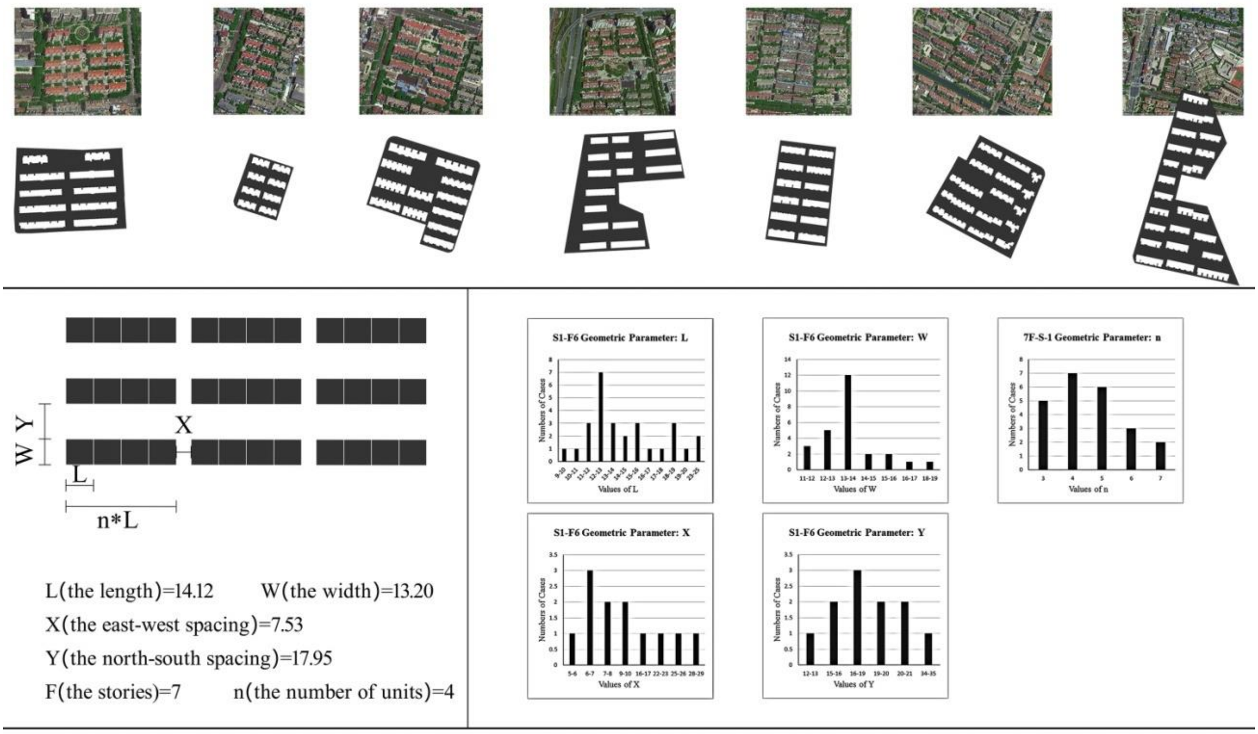


Figure 3. Thestatistical analysis of a multi-story parallel slab pattern (S1-F6)(above: the samples; the left bottom: the model of S1-F6 with geometric parameters; the right bottom: the statistical study of the geometric parameters.)

The geometric parameter values of various patterns are statistically measured following the above mentioned procedure, and all the 18 standard models of the fabric patterns are quantitatively defined (Table 2).

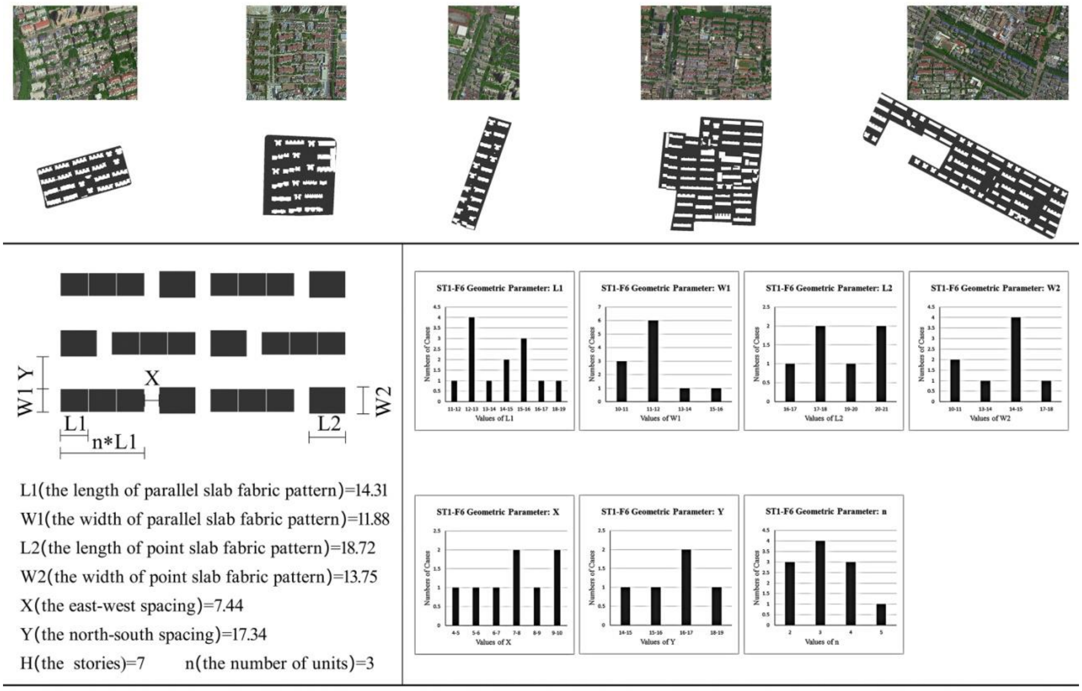


Figure 4. Thestatistical analysis of amulti-story point-slab pattern (ST1-F6)(above: the samples; the left bottom: the model of S1-F6 with geometric parameters; the right bottom: the statistical study of the geometric parameters.)

Validation of the patterns

The gross value of housing fabrics in a certain range, like density (FAR, floor area ratio), land coverage, are not corresponding to all the patterns, but only to fewof them. For example, the low-rise residential areas usually have FAR of about 1; the multi-story residential areas usually have a FAR of maximum 2; if the density of a high-rise residential area is 2, then it is not feasible, because it fails to explore the economic value of the plot fully, and would not exist in the real estate market. Comparing to the geometric parameters, the gross parameters of housing fabrics are more fundamental and essential. The fabric models based on the statistical study of geometric parameters need to be verified on the gross level.

The most common gross parameters of housing fabric are FAR, land coverage and average height, which are adopted as the land developing index by urban planning bureau in China. The three parameters mutually have internal correlations.

In order to present and study these three gross parameters effectively, comprehensively and simultaneously, Pont, M.B. and Haupt, Phave invented a useful chart tool, namely Spacemate. It is made with two basic coordinate axes, FAR coordinate axis and land coverage coordinate axis. Spacemate can be imported with an additional axis, average height, in the form of a slope line because of the functional relationships between the average height and the two above-mentioned factors. Therefore, any plot with any kind of a building on it, can be represented as a point in Spacemate. De Pont, et.al. have studied residential plots in the Netherlandsand disclosed that the residential buildings of the same type located in the same cluster in Spacemate (Pont and Haupt, 2004; 2010).

For this research, Spacemateprovides a useful tool for verifying astandard model on a fabric gross level. If it can be proved that the standard model and correspondingreal samples are distributed in the approximate region (namely belonging to the same cluster) in Spacemate, the validity of the modelsis verifiedon the gross level.

The multi-story parallel slab pattern is still taken as an example(Fig.5).

Three plots from the samples groups are selected as the test cases, that represent typical small, medium and large plots. A standard model of a multi-story parallel slab pattern (S1-F6) respectively hatch (fill in) the plots to obtain three new samples (marked with ‘*’ in Figure.5).The new samples are compared in pairs to the three original cases in Spacemate. All the three pairs of the samples are found to be distributed in approximate spaces. It means that the standard model can representthe real cases to a certain degree on fabric gross level, and its validity has been proved.

Table 2

The qualitative definition of the 18 typical patterns

T1-F3		L=13.37 W=14.23 X=13.90 Y=14.84 H=3×3	**S1-F11**		L=18.04 W=12.48 X=17.74 Y=36.75 n=3 H=11×3
T2-F3		L=16.50 W=15.10 X=12.40 Y=4.01 H=3×3	**S2-F11**		L=16.70 W=12.50 X=8.75 Y=13.07 n=3 H=11×3
S1-F6		L=14.12 W=13.20 X=7.53 Y=17.95 n=4 H=6×3	**T2-F11**		L=22.20 W=18.80 X=2.48 Y=13.29 H=11×3
S3-F6		L=10.92 W=12.06 X=8.91 Y=19.89 A=5.26 n1=3 n2=2 H=6×3	**S1-F18**		L=23.80 W=13.30 X=25.94 Y=51.38 n=2 H=18×3
S4-F6		L=10.92 W=12.46 X=26.25 Y1=22.50 Y2=29.20 θ=5.95° n=5 H=6×3	**S2-F18**		L=26.60 W=13.30 X=6.70 Y=24.90 n=2 H=18×3
S5-F6		L1=9.70 W1=10.67 L2=10.50 W2=8.63 X=7.50 Y=19.14 n=4 H=6×3	**T2-F18**		L=27.98 W=27.97 X=11.31 Y=8.35 H=18×3
ST1-F6		L1=14.31 W1=11.88 L2=18.72 W2=13.75 X=7.44 Y=17.34 n=3 H=6×3	**S1-F29**		L=31.90 W=13.80 X=48.37 Y=41.55 n=1 H=29×3
T1-F6		L=16.37 W=14.24 X=8.50 Y=19.74 H=6×3	**S2-F29**		L=32.51 W=14.38 X=1.55 Y=32.07 n=1 H=29×3
T2-F6		L=15.65 W=14.17 X=-0.60 Y=10.29 H=6×3	**T2-F29**		L=26.81 W=24.72 X=11.36 Y=12.65 H=29×3

The 18 patterns are verified one by one using the same method mentioned above(Fig.6). Generally, the samples of standard models are located in the cluster space formed by real cases; in term of details, the samples of standard models are basically located approximately to their corresponding real samples. Thus, it has been proved that all the standard models of fabric patterns are valid in the gross level.

Figure7.shows a real residential community, called Sample M. As we can see, any one of the 18 patterns cannot solely represent its fabric feature. This is because it is a mixed-fabric

residential community. In fact, sample M is not an orphan case, on the contrary, there are a lot of mixed-fabric residential communities in the real world, which are mixtures of 2 or 3 types of fabric patterns. For each of mixed residential cases, there is an implicit sub-division to divide the community into several small fabric areas with different patterns. According to this sub-division logic, the sample M is divided into two sub-plots, plot-a and plot-b. Pattern S1-F11 and Pattern T2-F11 are adopted to fill in the corresponding sub-area, and a new mixed case is produced. The gross data analysis is conducted to this pairs of cases. Two groups of gross data, one from the original case and the other from the standard-model-hatch case, are obtained (Fig.7). Moreover, the gross data from each sub-areas are added together to produce the third pairs of data, each of which in fact is the gross data of the whole community. As it can be seen in Spacemate, the third group of data is well-matched thatverifies the validity of the fabric models for the mixed residential fabric. This verification reveals that thenature of mixed housing fabric is the hatching with the sub-areas by different fabric patterns.

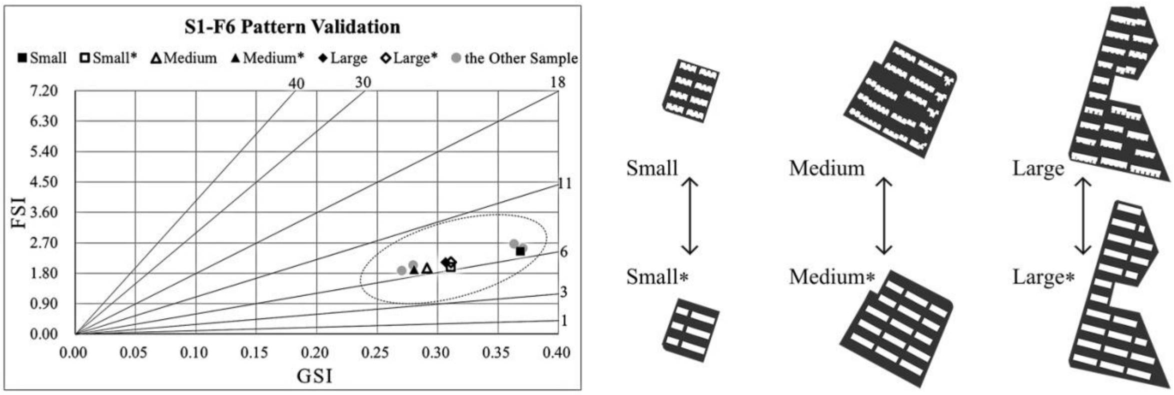


Figure 5. Validation of the multi-story parallel slab pattern (S1-F6) in Spacemate

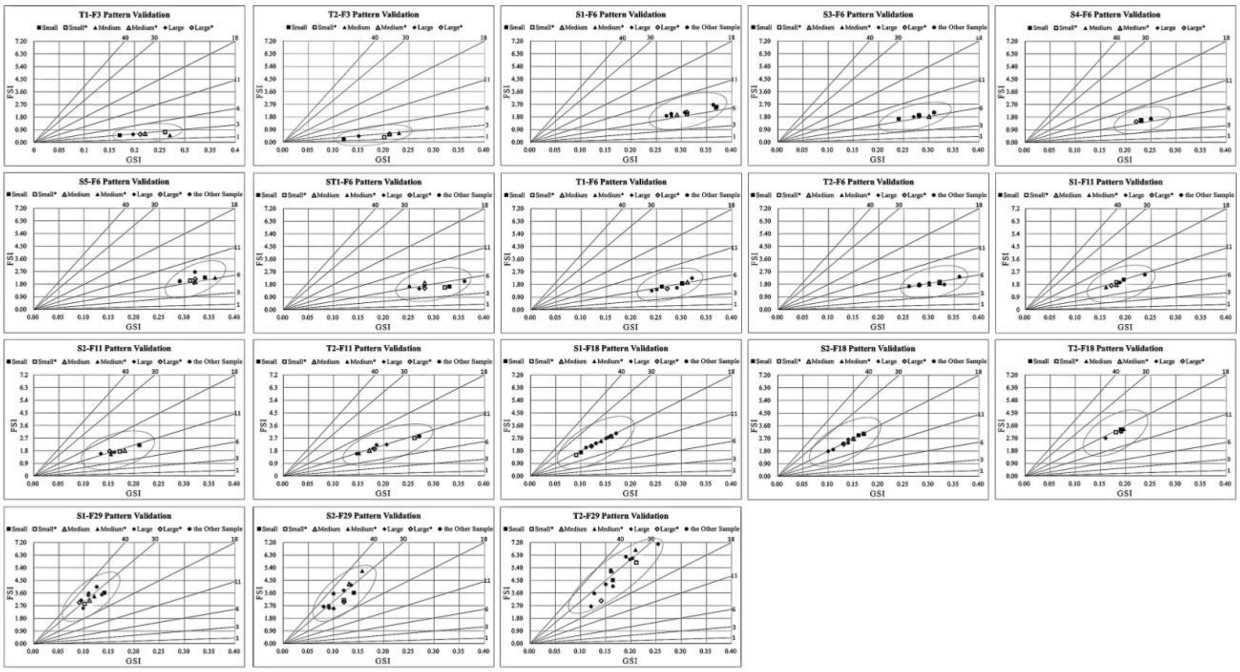


Figure 6. The validation of all the 18 patternsin Spacemate

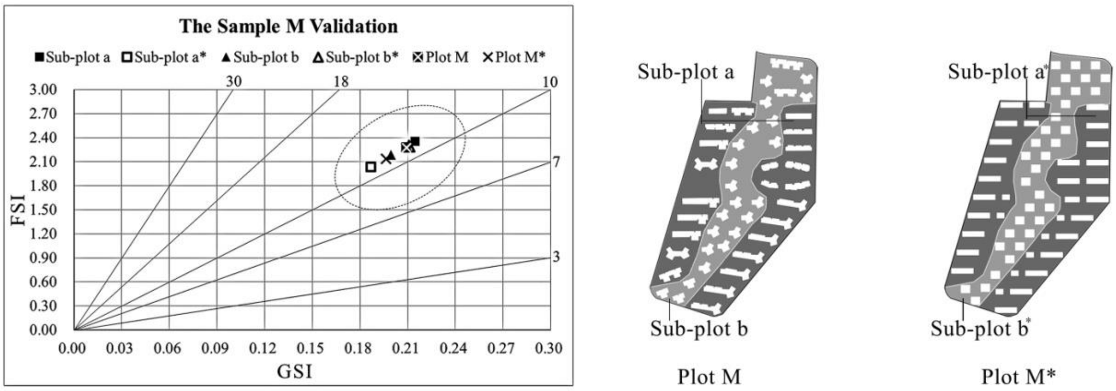
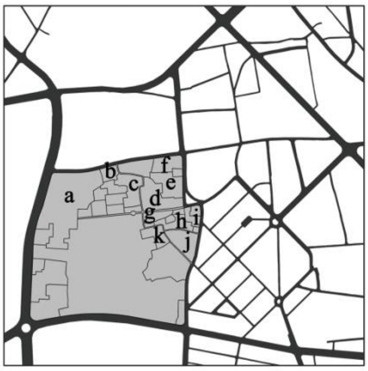
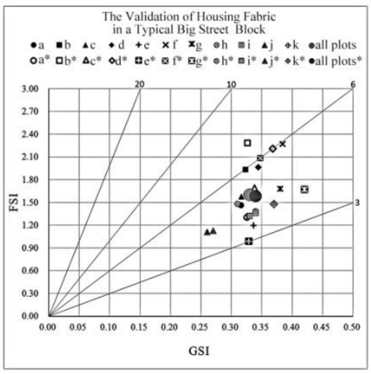


Figure 7. The validation of a mixed-fabric residential community (Sample M) in Spacemate



(a)the location of the block

(c) the housing fabrics with (right) and wihout (left) plot lines



(b) the validation in Spacemate

(d) the housing fabrics replaced by standard patterns with (right) and wihout (left) plot lines

Figure 8. Housing fabrics replacement with the standard patterns in a typical big street block

Summary and discussion

In this paper, Nanjing is taken as the case study city. 114 pieces of modern housing fabric samples from Nanjing, have been selected, classified, and statistical studied, from which, 18 typical modern housing fabric patterns have beenidentified and quantified. They lay a foundation for the further precise and quantitative urban morphology research. As mentioned above, these 18 patterns (in particular the values of geometric parameters) have certain territoriality. Values need to be adjusted before applied to specific territories.

Finally, we would like to end this paper with a discussion of an interesting case shown at the beginning of this paper. Let's focus on the big block at the bottom of the case area (Fig.8-a).

Operation of replacing fabric with standard patterns is conducted: non-house buildings in the block are reserved, while the housing fabrics on residential plots are replaced with the corresponding fabric patterns(Fig.8-d). The urban fabrics before and after the replacement are compared. First, they are visually consistent to a certain degree; second, conformity is observed in terms of the land gross value(Fig.8-b). Another interesting point is that, it is very difficult for us to predict the accurate shapes and positions of plots according to the variations of the fabrics themselves, if plot lines are hidden (see the most right colomn in Fig.8).

This case re-confirms the validity of the fabric patterns. More importantly, itextends the discussion to the following argument: housing fabricsare formed by the hatching of diversified plots with different fabric patterns. To some estend, fabric patterns overcome the irregularity of Chinese cities (in particular the inner urban areas) in aspects of plots and street blocks. They contribute to an urban morphological background with a relatively homogeneous quality. Not street blocks, nor plots, but patterns are the nature of modernhousing fabrics in Chinese cities.

Acknowledgement

This paper is supported by Chinese National Science Foundation (51538005, 51578277).

Reference

1. Conzen, M. R. G. (1969). *Alnwick, Northumberland: A Study in Town-plan Analysis* (Institute of British Geographers).
2. Pont, M.B, Haupt, P. (2004). *Spacemate: The spatial logic of urban density* (Delft: Delft University Press).
3. Pont, M.B, Haupt, P. (2010). *Space matrix: Space, Density and Urban Form* (NAi Publishers).
4. Lü, J, Peter, G. R, and Zhang J. ed. (2001). *Modern Urban Housing in China: 1840-2000* (Prestel).
5. Deng, S andWang, Z. (1996). *Data set of residential area planning and design* (China Architecture & Building Press). In Chinese.
6. Zhu C., Wei, H. and Long, H. (2011). *The Design Theory of Residential Buildings* (China Architecture & Building Press).
7. Hu, W (2006). *Residential Area Planning Principle and Design Method* (Construction Industry Press).
8. Huang, Y. and Zhu, P. (2016) 'Study on the Correlation between Density Control and Perceived Density in Urban High-density Residential Areas', *Time+Architecture June 2016*,50-59. In Chinese.
9. *National StandardGB50352-2005(2005), General Principles of the Civil Building Design*(Architectural Industry Press).In Chinese.
10. *NationalStandardGB50096-2011(2011), General Principles of the Residential Building Design.*(Architectural Industry Press).In Chinese.
11. *National StandardGB50016-2014(2014), Code for Fire Protection Design of Buildings* (Architectural Industry Press). In Chinese.