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PII: S0167-739X(17)31227-X
DOI: https://doi.org/10.1016/j.future.2018.02.017
Reference: FUTURE 3988

To appear in: *Future Generation Computer Systems*

Received date : 12 June 2017
Revised date : 8 February 2018
Accepted date : 12 February 2018

Please cite this article as: X. Li, S. Cheng, Z. Lv, H. Song, T. Jia, N. Lu, Data analytics of urban fabric metrics for smart cites, *Future Generation Computer Systems* (2018), https://doi.org/10.1016/j.future.2018.02.017

Data analytics of urban fabric metrics for smart cites

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ABSTRACT: Comprehensive understanding of the built environment, especially the urban form, is a prerequisite for building a smart city. Data analytics of urban fabric metrics using quantitative methods is critical to understanding a city's complexity. This paper aims to study urban fabricusing comprehensive computation methods. A series of morphological indexes of urban blocks are established to measure the blocks’ overall features and subtle differences. This study uses multiple statistical methods with computation techniques and machine learning to fulfill factor analysis and clustering to classify major block types and their spatial distribution, and this study aims to precisely position the important continuous zone and fracture within the study area based on a geo-information system (GIS), effectively revealing the potential morphological order of different block types in the urban fabric. The study provides a scientific and accurate basis and technical support for the optimization of urban construction. It has important and practical significance for promoting the scientific and reasonable implementation of a new type of urbanization.

KEY WORDS: urban morphology; urban fabric; block unit; clustering; data mining

1. INTRODUCTION

Urban fabric not only embodies the characteristics of environmental structure for a certain period but also contains profound social and economic relations. A large amount of information flow that mirrors history, politics, economy and culture has been materialized and preserved through the characteristics of urban fabric and evolved into the essential history of urban development. Since the 1980s, the urbanization rate in China has increased from approximately 20% to more than 50% [Peng 2011; Bai et al. 2014]. Along with the large scale and high speed of development, the urban fabric of many Chinese cities has been destroyed. For instance, continuity and integrity of the cityscape has been weakened, urban characteristics have been gradually lost, the quality of urban space has sharply declined, and the function of the urban fabric as the organization of public activities has been increasingly weakened. Therefore, a series of urban problems have forced people to think about how to operate cities in a smart way. Since 1990s, the Smart Growth Movement has gradually received global attention and developed as a new paradigm of Smart Cities (SCs) [Harrison & Donnelly, 2011]. Although it is difficult to have a clear consensus on the term SC and what its defining attributes are, there is widespread agreement about the fact that SCs are characterized by a pervasive use of information and communication technologies (ICTs), which, in various urban domains, help cities make better use of their resources [Neirotti et al., 2014]. However, the meaning of smartness in the urban or metropolitan context not only entails utilizing cutting-edge ICTs but also focuses on the ultimate purpose of using them, as understanding the nature of the urban form to improve city livability [Nam & Pardo, 2011]. Therefore, the adoption of smart technology benefits urban management and relevant policy-making. Machine learning is one of the growing ICTs that could be very beneficial for this requirement.

In recent years, the notion of SCs has gradually emerged as an important strategy for rethinking our attitude toward the built environment. With the rapid development of computer technology and Internet technology [Ahmed, et al., 2012, 2016], the "information-society life paradigm" has become a new research focus driven by data. The arrival of the "Big-Data Era" and the increasing maturity of information processing and information technology not only provide favorable conditions for the research on urban fabric and shape but also promote the transformation of the traditional architecture research to the measurement informatization [Bouk, et al., 2017; Rani, et al., 2017]. A variety of measurement methods on urban analytics have been introduced into research on urban fabric [Batty 1997, 2005]. The space syntax is widely utilized to describe the accessibility and overall characteristics of the urban structure [Batty 2002; Perver et al. 2008]. Moreover, the nature of land use, land value, construction intensity, spatial density and other social and economic attributes could be also incorporated when considering urban fabric studies [Kim and Dong 2002]. By integrating a series of parameters such as building density, building floor-area ratio, building average height, and open space, Pont [2007] established a graph called Space-mate to evaluate the relationship between the building density and urban morphology to directly reflect the characteristics of buildings and urban forms defined by the different building density indexes. In addition, some scholars put forward the framework of reverse process modeling and estimated the parameters and rules needed in process modeling through a given output target [Vanegas et al. 2012]. The goal is to formalize the modeling process as a probabilistic inference of grammar spanning space and to define an objective function to measure the similarity between the target model and the configuration parameters [Aliaga et al. 2008].

Although scholars and the mass media often refer to the urban fabric, people are more likely to apply it as a vague concept. Previous studies on urban fabric have focused on its conceptual definition; prototypical and spatial descriptions; spatial and temporal evolutions; and correlation with urban activities [Liu et al. 2014; Whitehand and Morton 2003; Gurer 2012]. It has also been argued that the visual aspects of urban space, such as buildings, open space, and street scenery, could distinguish cities, indicating the possibility of a quantitative method to study urban fabric by considering the size, shape, form, and relative allocation as a whole [Proshansky 1983; Li et al. 2016]. In terms of research methods, traditional research mostly adopted mental image analysis, Gestalt figure-ground analysis, architectural typology and other qualitative analysis methods. So far, some computational methods and tools have been available for indirect urban fabric analysis, including space syntax [Conroy-Dalton 2003; Franz and Wiener 2008], Isovists analysis [Batty 2001; Llobera 2003], walkability [Ewing and Handy 2009], and density-based quantitative analysis [Pont 2007]. Most of these attempts were constrained to delicate measures of urban fabric properties that do not take buildings into account, and some outputs are still difficult to interpret from an architectural and urban perspective. In Gil's trial, a method was presented to facilitate the application of urban typomorphology studies to urban design practices by assessing the attributes of a given urban area with data mining techniques to reveal the block and street types. At the core of the proposed method was the k-means clustering technique [Gil 2012]. However, this method could not prevent multicollinearity among the selected attributes of predefined formal characteristics and might cause information redundancy and lead to unexpected biases in the results.

Therefore, this paper uses the Hankou riverside area as an example for establishing a series of geometric morphological indexes based on the block unit. In this paper, using machine learning and statistical methods, morphological indexes were conducted with factor dimensionality reduction and clustering analysis to realize the effective classifications of block units. Additionally, a geo-information system (GIS) was utilized to visualize the spatial distribution rule in order to analyze the morphological rule and information map of different types of block units in the urban fabric. In this way, we could accurately grasp the complexity and relevance of the urban fabric.

2. SELECTED CASE AND DATA PREPARATION

The research herein targets the Hankou riverside area, which is the important historic street block in Wuhan, China. The corridor-shaped area is bounded by Yanjiang Avenue, Zhongshan Avenue, Jianghan Road, and the second Yangtze River Bridge and is approximately 4 km long, covering an area of approximately 218 hectares. In 1861, Britain, Russia, France, Germany, and Japan established concession districts here successively. Since then, this area has gradually developed into an important industrial and commercial center for the three towns of Wuhan and even China. This area is an important cultural carrier of historical changes in modern and contemporary times in Wuhan. The historical style has largely been preserved, and a large number of important historical buildings and historical relics are concentrated here, including banks, consulates, customs buildings, halls, churches, clubs, and other institutional buildings that were constructed during the concession period as well as old-style Lifen, apartments, private residences, officers' quarters, amalgamated dwellings and other modern residential buildings. After the establishment of new China, ownership of the original buildings was redistributed through means such as confiscation, expropriation, requisition, and purchase. On the one hand, the original housing cannot meet the needs of the large influx families in the region. As a result, residents have added onto or modified these buildings. On the other hand, some plots have been removed to make way for the establishment of different types of new public buildings, dormitories, apartments, commercial housing and other residential buildings, which has caused the original block fabric to change. Therefore, this area has a strong historical continuity and mixes different building types from different periods. The fabric morphology has a certain representativeness, reflecting the historical context of urban morphology and fabric development in Wuhan. Based on the large volume of on-the-spot investigations and research, as well as the status analysis, the total 83 urban blocks in this area are selected and numbered from #0 to #82. All of the maps have been checked against the ground truth for land use, plot boundaries, and other existing conditions to provide a proper match.

The method involves three main phases: representation, analysis and description [Witten and Frank 2005]. The representation phase involves preparing the geometric data of urban blocks with building footprints and selecting predefined morphological indexes. The selected indexes are calculated in GIS for comparison, analysis and visualization. The selection of shape indicators is important for describing the urban fabric because the shape indicators will carry tailored meanings that address specific aspects of the urban fabric and can be used to obtain useful information. In our case, the selection of indexes mainly focuses on geometric, structural, and physical characteristics of the urban fabric, and multiple morphological indexes are combined to represent different aspects of the urban fabric and produce an integrated overview [Conzen 2010].

3. METHOD

Fig. 1 shows an overview of the workflow of our method. A step-by-step description of data extraction and analysis follows below. First, the shape file of the selected area is obtained. Morphological indexes are defined precisely with their formulas. After the morphological indexes are calculated, some descriptive statistical methods are used to create a general picture of the study area. Next, a correlation matrix of selected indexes is built to test the potential influence in pairs and indicate the degree of multicollinearity among these morphological indexes. Statistical methods are then used to simplify these indexes into a small number of key factors that are mutually independent. After, unsupervised machine learning is applied for clustering analysis to know more about the typomorphology and the distribution pattern in the study area.

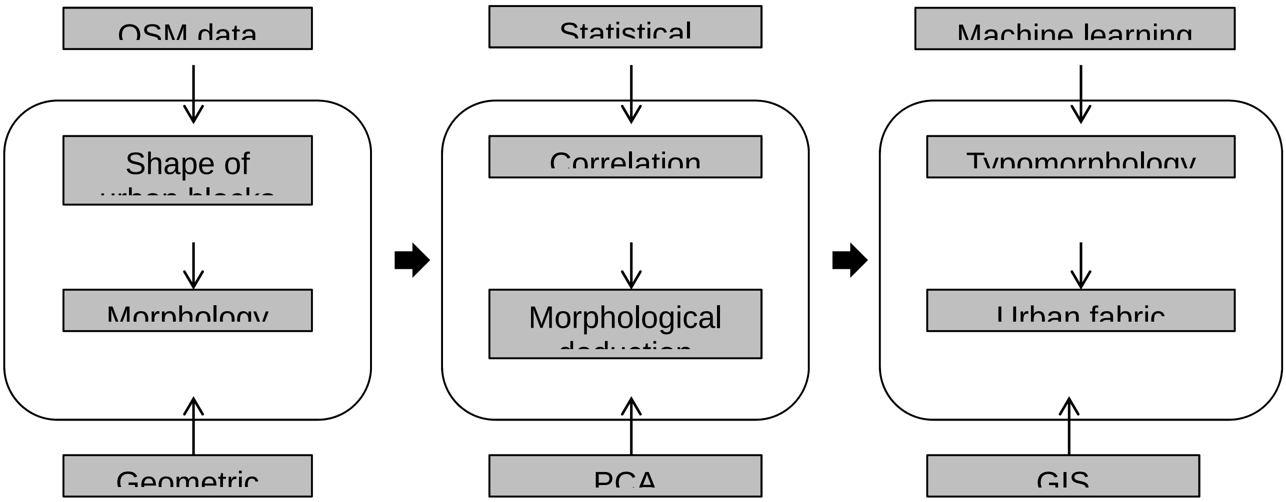


Figure 1. The workflow of urban fabric analysis

4. MORPHOLOGY INDEXES OF BLOCK UNIT

Urban fabric can be expressed as urban texture or urban grain. It projects the elements of the specific coordinate system in order to obtain the relative organizational form and spatial syntagmatic relation of built elements [Ratti & Richens, 2006]. Lynch [1984] took “fabric”, “density”, and “accessibility” as the main characteristics to define the urban performance, and he argued that fabric was an effective tool for reflecting the overall urban space morphological characteristics, saying that fineness and uniform degrees have an important influence on the morphological characterization of urban fabric.

One of the main difficulties in studying urban fabric is how to accurately describe its morphological character. The frequently utilized morphological description indexes (such as building density and floor-area ratio) cannot fully reflect the difference of different fabric morphologies. Although Pont [2007] combined building density, building floor-area ratio, average building height, and open space rate to reflect the building and urban morphological characteristics defined by different building density indexes, it is not comprehensive enough. Therefore, this paper has attempted to describe, compare and analyze the block units by establishing corresponding geometric morphological indexes to characterize the overall morphological characteristics and internal differences of the block units. The index system is divided into three groups: shape index, texture index, and density index (Tab. 1). All the indexes are calculated in ArcGIS 10.3 for visualization. For instance, the value distribution of the block morphological index can be compared simultaneously among the five different concession areas. Some morphological index values are distributed evenly (Fig. 2e, 2g) while others are relatively dispersed (Fig. 2b, 2d). In addition, in this case, the morphological index values are mostly even distributed with some significant outliers (Fig. 2f). As we can see, a block in the French concession area has the largest average building footprint. Some blocks in the Japanese concession area tend to have larger building footprints (Fig. 2a) than other concessions.

Table 1. The List of morphological index list

Code	Morphological Index	Description
X1	block area	
X2	weighted average building footprint	shape
X3	arithmetic average building footprint	
X4	building coverage	
X5	quantity of building	
X6	fineness	texture
X7	fragmentation	
X8	compactness	
X9	cohesion	
X10	average building height	density
X11	floor-area ratio	

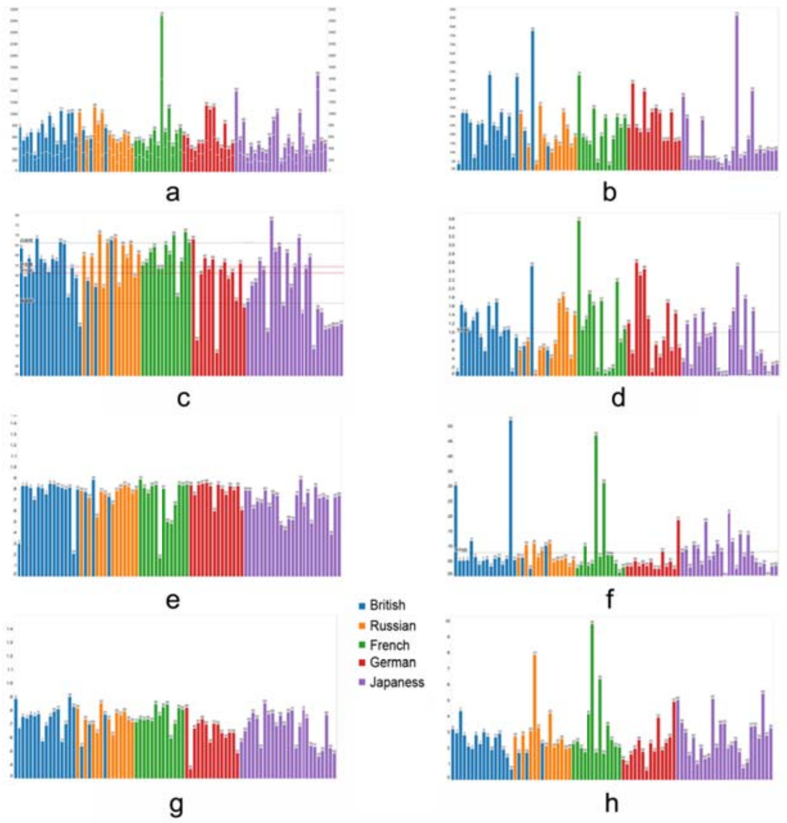


Figure 2. Statistics of morphological index distribution of 83 block units (a) mean area of building footprint (b) block area (c) building coverage (d) fineness (e) fragmentation (f) cohesion (g) compactness (h) floor-area ratio.

4.1 Building Coverage

Building coverage is a common measure for block density. Urban fabric often has a certain compact morphology. The concept of building coverage describes the area ratio that buildings cover on a certain plot. It reflects the relative quantitative relationship between the building entity and the external space and can initially define the fabric morphology as:

$$Density = \frac{\sum S_i}{S_B} \quad (1)$$

where S_i is the footprint area of each building within given urban block, and S_B is the area of the plot.

4.2 Compactness

Compactness is used to describe the allocation and spatial distribution of buildings within a plot. It could reflect how the geometrical center disperse into the surrounding area (Fig. 3). The formula for compactness is based on the gravity model [Thinh, et al., 2002], which measures urban sprawl and agglomeration as follows:

$$C = \frac{\sum \frac{1}{d(i,j)}}{N(N-1)/2} \qquad (2)$$

where $d(i,j)$ is the distance between raster cells, and N is the number of raster cells.

The formula should be normalized using a standard circle of the same size to alleviate the bias from different sample sizes. If the calculation is processed on a raster basis, the resolution of the raster should be uniform beforehand.

$$Compactness = \frac{C}{C'} \qquad (3)$$

where C is the compactness of the test urban fabric, and C' is the compactness of the standard shape.

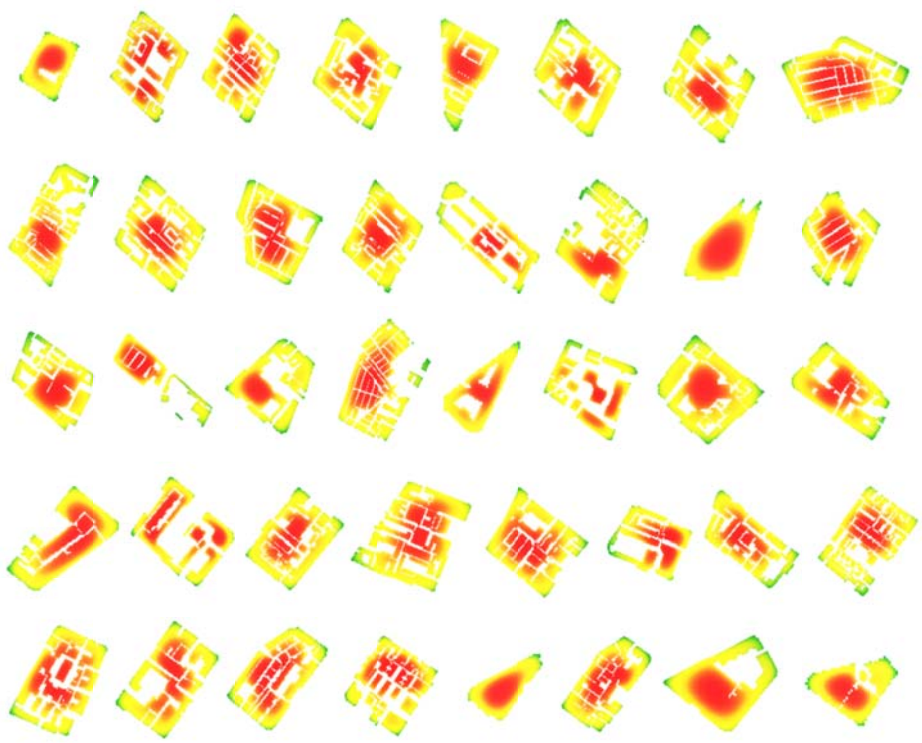


Figure 3. The raster distribution of compactness value in urban blocks

4.3 Fragmentation

Single buildings and community buildings reflect different fabric morphologies. With similar coverage and compactness, the fabric composition may reflect different numbers of buildings. An optimized perimeter-area ratio is often used to measure the complexity of a patch shape compared to a standard square of the same size, while alleviating the problem caused by different shape sizes. This fragmentation index has been widely used in landscape ecological research [Forman and Godron 1986]. Therefore, urban fabric fragmentation could be defined as follows:

$$Fragmentation = 1 - \frac{4\sqrt{S_i}}{P} \quad (4)$$

where S_i is the coverage of an urban block, and P is the sum of the building perimeters.

4.4 Cohesion

Cohesion can quantitatively describe the spatial state of the integrated and contacted building elements in the urban fabric. The calculation process is divided into three steps: Step 1, calculate the fragmentation degree. Step 2, set a distance threshold value; the single buildings smaller than the threshold will be conducted with spatial clustering and merging to generate a number of patch sets containing single buildings; and then calculate the fragmentation degree again. Step 3, carry out the standardization for the absolute value of the difference value calculated in the first two steps.

$$Cohesion = \left| F - F' \right| \quad (5)$$

where F is the fragment before shape aggregation, and F' is the fragmentation degree after aggregation.

5. EXTRACTION OF FABRIC MORPHOLOGICAL FACTOR

The correlation matrix presents a certain degree of multicollinearity among the fabric morphological indexes, namely, redundancy and overlapping of information (Tab. 2). Therefore, we need to simplify these indexes into a small number of key factors that are mutually independent, so that these factors cannot only comprehensively reflect the morphological characteristics of various aspects but also avoid information overlapping. By means of the principal component dimension reduction method, a few common factors can be utilized to explain the complex relationship among the multiple observation variables, and the computational formula is as follows:

$$\begin{cases} X_1 = a_{11}F_1 + a_{12}F_2 + \ldots + a_{1m}F_m + \varepsilon_1 \\ X_2 = a_{21}F_1 + a_{22}F_2 + \ldots + a_{2m}F_m + \varepsilon_2 \\ \ldots \\ X_n = a_{n1}F_1 + a_{n2}F_2 + \ldots + a_{nm}F_m + \varepsilon_n \end{cases} \quad (6)$$

where $X_1, X_2 \ldots X_n$ are the original morphological indexes. $F_1, F_2 \ldots F_n$ are common factors of all indexes. α_{ij} is the coefficient of the original index X_i on the common factor F_j. The factor load can be understood as the correlation coefficient of the original indexes and factors. $\square_i$ is a special factor, representing the part that cannot be explained by the factor in the original index. Therefore, the linear combination of common factor F_j can be utilized to replace the original morphological index X_i, and its expression is as below:

$$F_j = \beta_1 X_1 + \beta_2 X_2 + ... + \beta_n X_n \quad (7)$$

The simplified factor is not a new combination of the original variables. The original variables are divided into two parts, namely, the common factors and the special factors. The former is the part that is shared by all original variables, while the latter consists of the factors exclusively owned by each original variable. The factor load matrix is conducted with orthogonal rotation through the maximum variance method so the actor load of each factor is polarized to 0 or 1 by rotating the axis. In this way, the original indicators most closely associated with the factor can be better extracted. Table 2 shows that the factor load under the proposed method is more than 0.8, which makes the factor characteristics more significant (Tab. 3).

The necessary condition for an effective factor is that the initial Eigen values are greater than 1. Therefore, multiple fabric morphological indexes can be simplified as three main factors (Tab. 4) (Fig. 7). The first main factor reflects the amount of detailed information about the scale features and fabric of the block and is called the “scale detail synthesis factor”. The second main factor reflects the coverage rate and the concentration distribution trend of building patches and is called the “compact factor”. The third main factor reflects the average size of the building patches and is called the “patch scale factor”. Therefore, the main factors affecting the fabric morphology are the block size, the fabric density, and the scale of the building patches. The variances of these three factors accounts for 46.8%, 24% and 18.2%, respectively. The sum of the three factors can explain 89% of variance, and the representativeness is favorable.

Table 2. The correlation matrix of selected indexes (X1=block area, X2=weighted average area of building footprint, X3=arithmetic average area of building footprint, X4= building coverage, X5=quantity of buildings, X6= fineness, X7= fragmentation, X8= compactness, X9= cohesion, X10=average building height, X11=floor-area ratio)

	(X1)	(X2)	(X3)	(X4)	(X5)	(X6)	(X7)	(X8)	(X9)	(X10)	(X11)
(X1)	1										
(X2)	0.144 (0.194)	1									
(X3)	0.003 (0.977)	0.848**	1								
(X4)	-0.241*	-0.068 (0.54)	-0.207 (0.6)	1							
(X5)	0.73**	-0.167 (0.131)	-0.375**	0.258*	1						
(X6)	0.512**	-0.467**	-0.506**	0.254*	0.866**	1					
(X7)	0.543**	-0.335**	-0.495**	0.112	0.713**	0.661**	1				

				(0.314)							
(X8)	-0.231*	0.164 (0.138)	0.099 (0.372)	0.716**	0.074 (0.505)	0.048 (0.664)	-0.25*	1			
(X9)	-0.307**	0.222*	0.194 (0.079)	0.134 (0.229)	-0.341**	-0.314**	-0.745**	0.371**	1		
(X10)	-0.068 (0.539)	0.336**	0.526**	-0.523**	-0.381**	-0.418**	-0.387**	-0.357**	0.16 (0.149)	1	
(X11)	-0.111 (0.317)	0.337**	0.372**	-0.054 (0.625)	-0.208 (0.059)	-0.296**	-0.373**	-0.006 (0.956)	0.365**	0.758**	1

Table 3. Principal factor load

Morphological index	Un-rotated factor load			Morphological index	Rotated factor load		
	Factor1	Factor2	Factor3		Factor1	Factor2	Factor3
Quantity of buildings	0.923			Quantity of buildings	0.947		
Block perimeter	0.892			Block perimeter	0.860		
Block area	0.880			Block area	0.850		
Fragmentation	0.813			Fragmentation	0.818		
Fineness	0.802			Fineness	0.837		
Coverage		0.910		Coverage		0.925	
Compactness		0.779		Compactness		0.917	
Mean footprint area			0.894	Mean footprint area			0.956

Table 4. Matrix of Eigen values and variance of three main factors

Serial number	Initial Eigen value			Extracted square and loading			Rotated square and loading		
	Sum	Variance%	Total %	Sum	Variance%	Total %	Sum	Variance%	Total%
1	3.764	47.051	47.051	3.764	47.051	47.051	3.748	46.848	46.848
2	2.006	25.070	72.121	2.006	25.070	72.121	1.922	24.027	70.875
3	1.360	16.996	89.117	1.360	16.996	89.117	1.459	18.241	89.117
4	0.468	5.852	94.968						
5	0.198	2.481	97.450						
6	0.135	1.686	99.135						
7	0.039	0.493	99.628						
8	0.030	0.372	100.000						

Factors within the colored block is valid, and the others are invalid

6. CLASSIFICATION OF BLOCK UNITS

Unsupervised machine learning is good at clustering without knowing specific classifications beforehand. In fact, the basic task of unsupervised learning is to develop classification labels automatically. Unsupervised algorithms seek out similarity between pieces of data in order to determine whether they can be characterized as a group. These groups are termed clusters. Since the number of the specific type of block units cannot be predicted, the 83 urban block samples can be automatically grouped through the hierarchical clustering method at the beginning. Python programming and the "Integrated Development Environment" (IDE) are based on Canopy. According to the tree graph, the samples can be divided into twelve classes of the most compact block types (Fig. 5). Isovist Integration is calculated to understand the urban space and the spatial distribution of the same type of block unit was marked in the same area. The calculation is done in Depthmap with a 10-meter sampling grid. The data are loaded into ArcGIS for representation. Colors from red to green are used to represent high values and low values. The results reveal rich hierarchies of the urban configuration that define continuous spaces from public, semi-public, semi-private and private (Fig. 6). The results of hierarchical clustering were examined through the morphological analysis method based on the architectural typology. Moreover, we also combined their scale, morphology, fabric pattern, other shape information, and concession information for a comprehensive judgment. The results show that the hierarchical clustering method based on the three main factors can effectively classify fabric types of the block units in this area. Those urban blocks are classified into twelve different types that share some common features on size, shape of block outline, building pattern, and density (Fig. 5). The excessive block types obtained from the hierarchical clustering are not conducive to more generalized classification results. Based on the tree diagram of hierarchical clustering (Fig. 5), the results show that the clustering is roughly distributed in five general types. We can summarize the following five main types of block fabrics by K-means clustering (Fig. 4, Tab. 5).

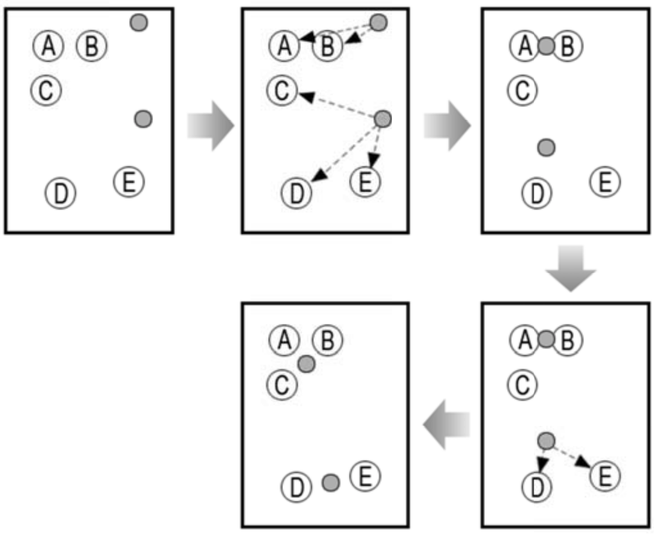


Figure 4. The diagram of K-means clustering process

Table 5. K-means Algorithm in Python

```
Data: Factor of Urban Block # import CSV file
df = pd.read_csv(path+fn, sep=';', header=None)
X_cols = [1,len(df.columns)]
X = np.array(df[df.columns[X_cols[0]:X_cols[1]]])

def A (a, b):
    x = []
    y = []
```

```
    for i in range(a, b):
        k_means = cluster.KMeans(n_clusters=i)
        k_means.fit(X)
        result = k_means.score(X)
        x.append(i)
        y.append(result * -1)
        print -result
    plt.plot(x, y)

def KMeans(k):
    km = cluster.KMeans(n_clusters=k, n_init=1000).fit(X)
    result = pd.Series(km.predict(X))
    result.name = 'Cluster'
    result = pd.concat([df[df.columns[0]], result],1)
```

The type-A blocks account for 23% of the total number (Fig. 7a). This type shows the phenomenon of polarization in the block size. For this type of block, the number of buildings is relatively small, and the buildings are mainly composed of scattered large patches. Therefore, there is little detailed information about the block fabric. The density and compactness of the buildings are moderate, and the fabric has a certain density. The buildings in this type of block are mainly modern high-rise residential buildings with centralized layouts, high-rise residential buildings with podiums, hotel and office complexes, and some early centralized landmarks. These buildings form a relatively loosely organized block fabric, consistent with the independent layout generally adopted in modern architecture. The overall fabric is relatively rough, so this type of block units can be summarized as “modern A”.

The type-B blocks account for 45% (Fig. 7a), forming the major fabric type in Hankou riverside area. For this type, the block size is moderate. The number of buildings and the fabric fineness degree are great within the block, and the fabric details are relatively rich. The fabric is also compact, and the porosity is low. The size of the building footprints in the block is moderate. The distribution of these blocks is relatively continuous, forming the main fabric features of this area. The building type is mainly old-style Lifen (local residential building), mixed with some important public buildings and all kinds of residential buildings of different ages. Due to the influx of a large number of people after 1949, the original buildings have been enlarged, remodeled and even removed. Although different types of new public buildings, dormitories, apartments, and commercial housing have been constructed, and the original block fabric has been changed to a certain extent, the fabric is still consistent and continuous, so it can be summarized as “the core block” in this area.

The type-C blocks account for only 8% of the total number (Fig. 7a) and are considered a minor type. These blocks are generally characterized by a rather large block size. The number of buildings inside the block is also great, and the fabric details are very abundant. The layout of buildings has a moderate degree of compactness. Additionally, the average size of building footprint is great. Therefore, this type of blocks can be summarized as "super blocks".

The type-D blocks account for 16% of the total number (Fig. 7a), with a certain universality. This type is mainly small and medium size blocks, and only a few buildings are within each block. The fabric details are also few. The building coverage in the block is low, and the layout is relatively loose and less compact. These blocks mainly contain all kinds of new residential buildings constructed in recent years (such as Wuhan Tiandi Commercial District). To create a relatively pleasant living environment, most of these buildings have a central courtyard, and the building coverage rate of the plot is generally low, with a high environmental potential and landscape quality. Therefore, these blocks can be summarized as "modern B".

The type-E blocks account for 8% of the blocks (Fig. 7a), a minority of the total. The first factor score of this type is low, due to the small scale of these blocks. Both the second and third factors are both at high levels, indicating that the building patches are small and compact, with high density and coverage rate. Buildings in these blocks are mostly low-rise dormitories, cottages and old houses. Around the block are two-story buildings, leaving narrow passages to the inner area. The environmental quality is poor, and the building layout is very compact. Therefore, this type of block units can be summarized as "traditional block with high density".

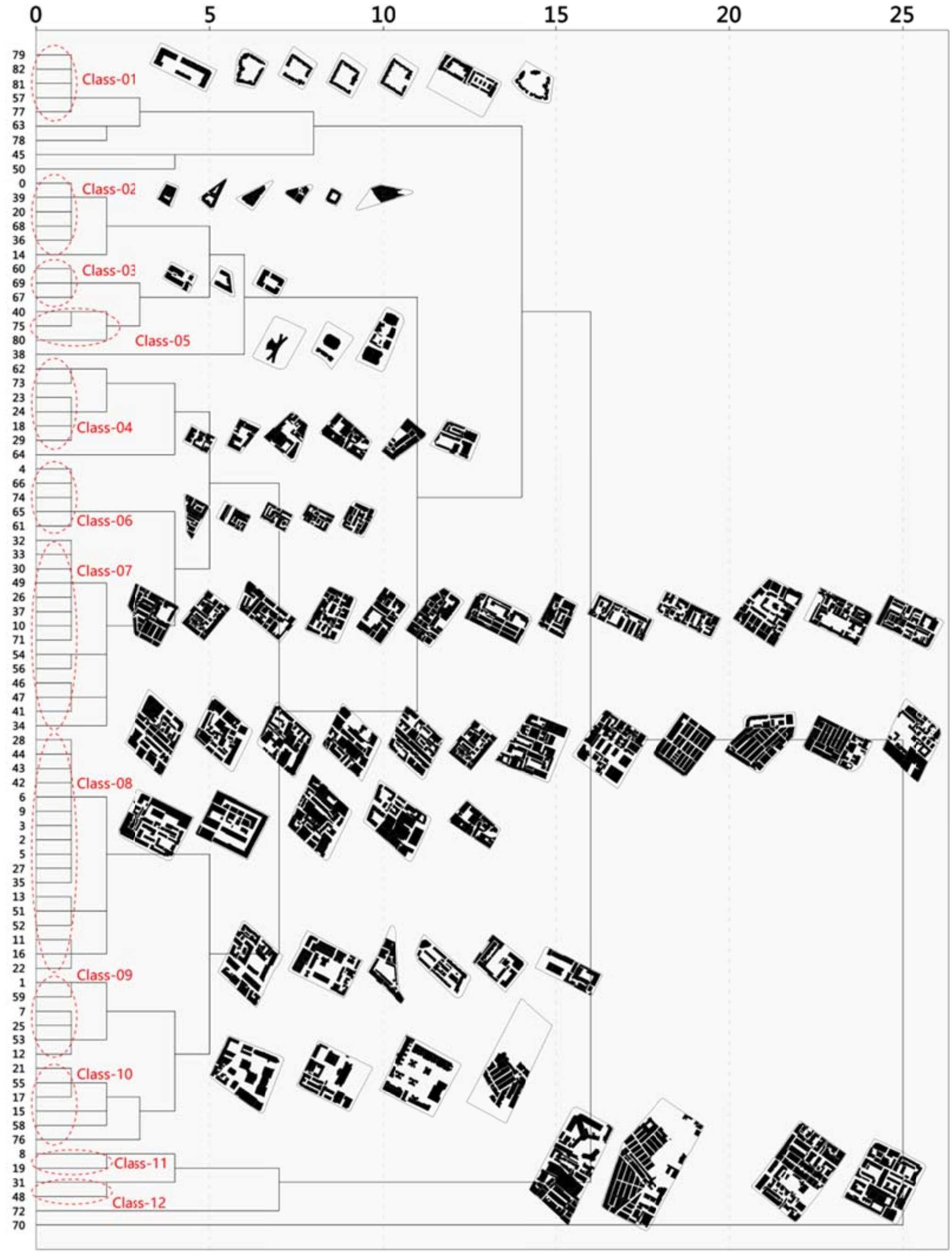


Figure 5. Hierarchical clustering and related block types

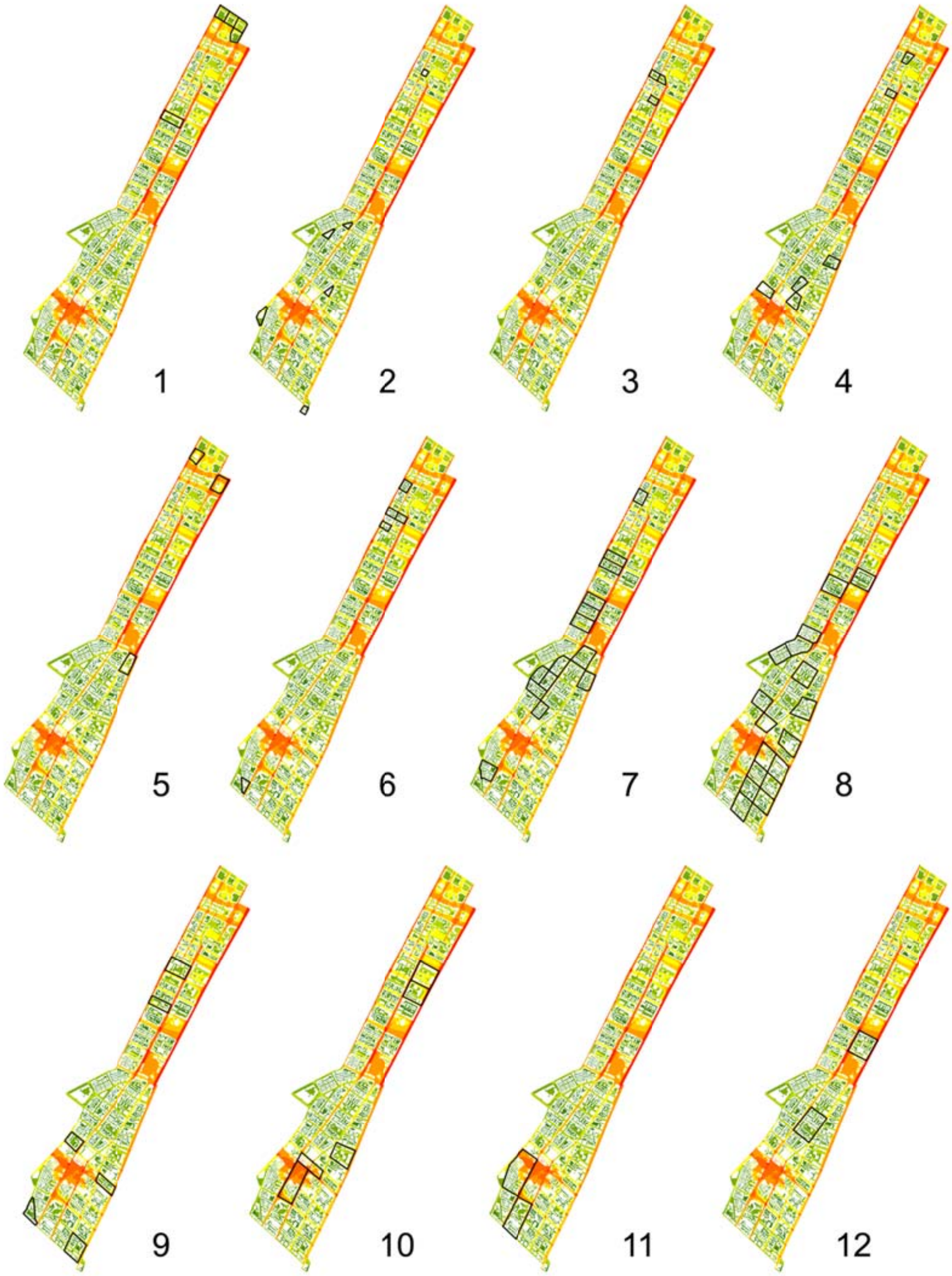
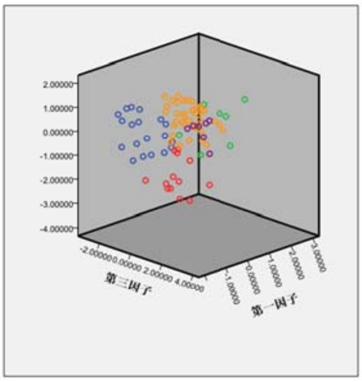


Figure 6. Spatial distribution of the same block units based on hierarchical clustering method



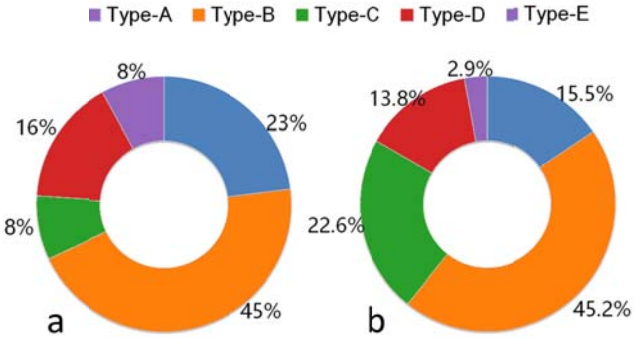


Figure 7. Percentage of the total area of block types (a)
Percentage of the number of block types (b)

7. CONTINUOUS ZONE AND FRACTURE ZONE

The information entropy can be used to describe the mixture of different block types in the selected area. The more ordered a system is, the lower its information entropy will be. In contrast, the more chaotic a system is, the higher its information entropy will be. Therefore, the information entropy is an important index to measure the degree of order for a system. The formula is as follows:

$$H(x) = -\sum \mathrm{P_i} \log \mathrm{P_i} \quad (8)$$

where H(x) is the mixed degree of objects. Pi is the probability of X_i.

Therefore, we can calculate the mixture of each concession area (Fig. 7). The result indicates (Fig. 8) that the urban fabric in the Russian concession area is composed of two major block types and is the most uniform on the whole with an entropy value of 1.17. The entropies of the French and British concessions are basically consistent. The heterogeneity of the urban fabric in these two areas is slightly higher with the entropy value of approximately 1.5. The block types of German concession and Japanese concession are very mixed. In particular, the entropy of Japanese concession is up to 2.15, the highest of the concessions, which reflects the phenomenon of fabric fracture caused by the large-scale urban renewal in recent years.

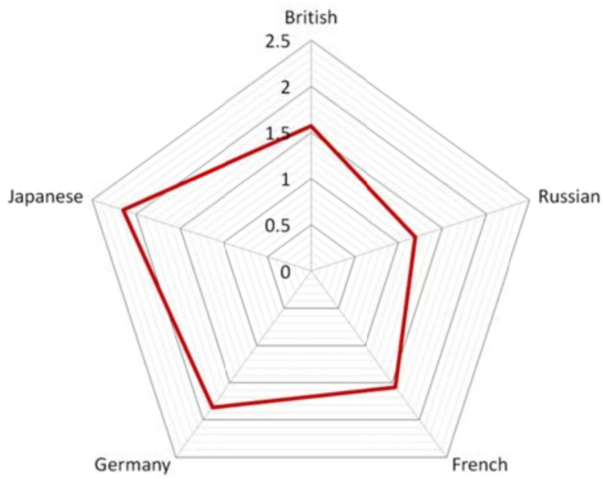


Figure 8. The entropy of block units in all concessions

We have projected the five major block types on the map in order to analyze their spatial distribution in the Hankou riverside area. In general, the "core blocks" constitute the basic fabric structure in this area (the continuous zone). The continuous zone starts at the original eight blocks initially established in the British concession along the Yangtze River. The continuous zone deeply develops into Russian concession at the junction of British and Russian concessions and further extends eastward along the blocks north of Shengli Street in the French and German concessions, forming a continuous backbone of the Hankou riverside area (Fig. 9), until it gradually disappears in the very mixed blocks of the Japanese concession area. For the Hankou riverside area, this continuous zone could potentially perform as the "featured axis" if it is carefully protected and organically renewed. The formation of the Hankou concession area changes the spatial trend along the Han River and gradually forms the development pattern along the Yangtze River. Therefore, for the selected area, extensive urban renewal adopting massive demolition of the original urban fabric should be prohibited, and transitional transformation should be carried out instead. The strategy of protection and utilization shall be taken to optimize the infrastructure, clean up illegal construction of temporary structures, and restore the original urban fabric. Based on the premise of protecting the unity of style, new elements shall be introduced into the city through a series of "fine city weaving" methods and by fully excavating the real value of the old buildings. New vitality shall be injected into the city through the functional replacement to meet the needs of modern life.

Except for the British concession, the continuity of the fabric of other blocks along the river gradually decreases, which undermines the historical unity of this area. In particular, the emergence of a number of fragmented modern blocks causes great differences to the original compact urban fabric. The huge high-rise buildings require large spaces for fire protection and lighting requirement, which compromises the continuity of the urban fabric. The modern architectural layout also reduces the interface density of the blocks and breaks the block boundary defined by the building. In addition to the favorable fabric continuity, a large number of important and outstanding historical buildings are preserved in these eight blocks. Additionally, there are many private residences and separate houses. These buildings have a high level of artistic and construction quality, and most of them are still in use.

There has been a large number of high quality public buildings in the Russian concession adjacent to the British concession. Because the main policy of the old city after 1949 was “full utilization and gradual transformation”, the historic blocks in Hankou were filled and complemented. As a result, quite a few low-quality buildings were constructed in the old city. At the same time, as the ownerships of most buildings were changed, so were the function and space. For instance, the former Russian consulate was converted into a hotel, and the former U.S. Navy youth club was utilized as a residence. In this way, the surrounding building environment was substantially changed. After the 1980s, the pace of urban construction in Wuhan began to speed up, and many Lifen and historical buildings were demolished. Modern high-rise buildings have been built up. These large-scale buildings with primitive structures destroyed the original urban fabric and damaged the integrity and unity of the Russian concession to a certain extent. Even so, the unity of urban fabric in this area is still the highest among the five concessions, and its entropy value is as low as 1.19. The Russian concession is likely to be neglected for its small scale and its location between the British and French concessions, which have buildings with more distinct characteristics. However, the “core fabric zone” occurs to turn in this area. Therefore, the Russian concession can play a key role as a link that will optimize the “continuous zone” to enhance the overall unity of Hankou riverside area.

The fabric type of the French concession is relatively uniform, and the entropy is 1.56. The French concession is comprised of gridiron roads and a few diagonal streets. Among the five concessions in Hankou, the French concession lasted for the longest time before being reclaimed by the Chinese government. A number of outstanding historical buildings have been preserved in this area, and the architectural style is mainly the classicism of the Roman Revival, characterized by rounded arches and pointed arches. The details reflect the rich characteristics of French culture. Today, many Lifen buildings are still well-preserved in the French concession, forming an urban fabric morphology with distinct characteristics. These Lifen buildings have good spatial order and layouts. The paths in Lifen are mainly pedestrian spaces with appropriate scales, which effectively avoid external interference. A large number of local residents live here, forming strong cultural characteristics of local residential blocks.

The fabrics of the former German and Japanese concessions became more mixed, and the uniformity has decreased. Although a few old-style Lifen streets are preserved in the blocks in the north of Shengli Road within the German concession, the area along river has been interrupted by a variety of modern blocks. In the Japanese concession, except for the uniform residential blocks at the north end of Wuhan Tiandi, large and small blocks of different types mix with each other, which results in the area being caught in the chaos of fabric. In particular, a variety of large-scale real estate and commercial complex development projects have been constructed in recent years, and the original urban street system cannot adapt to the layout of these huge blocks along the river, which has intensified the fracture phenomenon of the urban fabric.

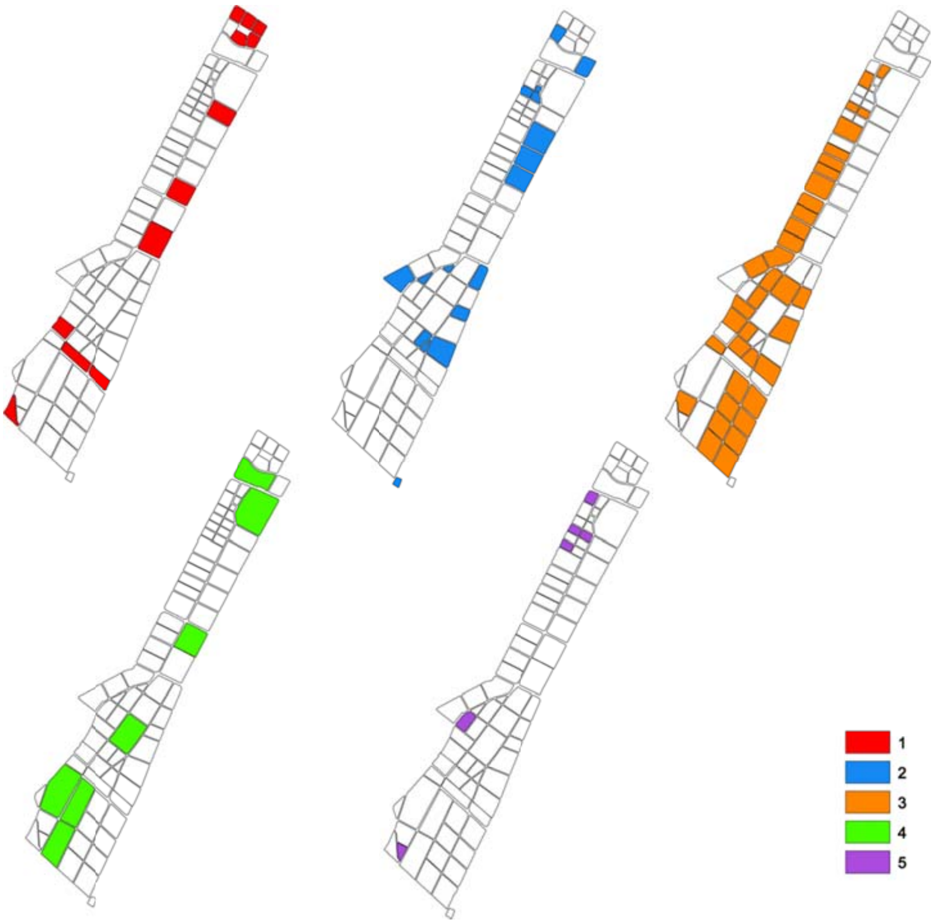


Figure 9. Mapping of the major block types and distribution pattern

8. DISCUSSION AND CONCLUSION

The notion of SCs is facilitating the transformation of traditional architectural research to a more precise and smarter stage as required by the information-society life paradigm . To understand the urban fabric, this paper presents a comprehensive method for conducting urban typomorphological analysis of urban blocks. The richness of the urban fabric is valuable for a city and is an important condition for healthy city life. Since the 1980s, many Chinese cities have suffered from the facture of environmental contexts and the lack of a sense of belonging due to the negligence of coordinated development of regionalism, culture and contemporaneity. Sustainable development will need to focus on the protection and continuation of the urban fabric with continuous and unified characteristics. In view of this phenomenon, this paper analyzed the typical fabric characteristics of the Hankou riverside area based on intelligent computation methods. A series of morphological indexes of urban blocks were established to measure their overall features and subtle differences. Factor analysis and clustering analysis were involved to automatically classify major block types and their spatial distribution. The described methods precisely position the important continuous zone and fracture within the study area, effectively revealing the potential morphological order of different block types in the urban fabric. We found that there still exists an important core fabric continuous zone in this area. For the area along the Yangtze River in Hankou, the fabric of different streets has similarities and differences to a certain degree. This contradictory unity is an important factor that allows the region to retain its distinct characteristics and strong flavor of life. The large scale of reconstruction in the city, especially in the historic area, is undoubtedly worthy of reflection. In particular, in the current incremental planning tends to be saturated, so the urban fabric morphology must be further interpreted and studied in order to carry out reasonable and effective artificial interventions and lay good foundations for the further development of positive and healthy lives in the area. The study provides a scientific and accurate basis and technical support for the optimization of urban planning. This research has important and practical significance for promoting the scientific and reasonable implementation of this new type of urbanization. For further improvement, we should consider urban fabric with three dimensional features. More social and economic factors would be involved as complementary support to interpret the formation process of urban fabric.

FUNDING: This work was supported by the National Natural Science Foundation of China (No. 51408442) and the Science Project of Ministry of Housing and Urban-Rural Development of PR China (No. 2017-K8-044).

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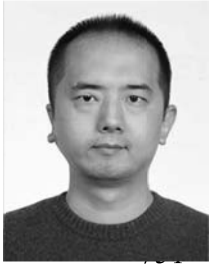

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1. A series of morphological indexes of urban blocks are established to measure their form features and subtle differences.
2. Multiple statistical methods with computation techniques are used to fulfill factor analysis and clustering analysis to classify major block types and their spatial distribution, and precisely position the important continuous zone and fracture within the study area based on GIS platform, effectively revealing the potential morphological order of different block type in urban fabric.
3. The study provides scientific and accurate basis and technical support for the optimization of urban construction. It has important and practical significance to promote the scientific and reasonable implementation of the new type of urbanization.