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Assessment of Urban Fabric for Smart Cities

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ABSTRACT Comprehensive understandings to the built environment especially the urban form is a prerequisite for building a smart city. This paper is based on computational methods to examine the urban fabric of Hankou, China, as a case study. Quantitative and comparative analyses are involved to understand the characteristics on the block scale, where massive demolition and new construction coincide with the existing historical context. Five urban fabric indicators are defined (i.e., density, compactness, fragmentation, variance, and cohesion) to conduct a case study for the 83 selected blocks using geographic information system tools and statistical analysis. Distribution patterns and correlations between these indicators are analyzed. Comparisons are made between typical blocks with high, median, and low fabric densities using comprehensive fabric indicators. The research results indicate that the organic order of the original urban fabric is facing damage, especially from arbitrary demolition, overinfilling, and spontaneous encroachment. Finally, this paper discusses how retaining the urban fabric makes the city a vibrant place to live. The sustainable development of a city should attach great importance to the protection and continuation of local characteristics of integrity and authenticity. The described analytical methods could contribute to the optimization of urban design strategies for future smart cities.

INDEX TERMS Smart cities, GIS, urban fabric, Hankou, hybridity, Chinese urbanization.

I. INTRODUCTION

In the past two decades, the notion of Smart Cities has gradually emerged as an important strategy to rethink our attitude towards the built environment, especially when modern cities are facing challenges of losing characteristics [1], [31]. As a representation of urban form, urban fabric is a major discourse in urban studies in the past decades [9], [12], [32], [35], therefore it is essentially important to involve urban fabric assessment for building a smart city. However, after the industrial revolution, mechanical improvements facilitated economical and quick construction methods. Due to the urgent needs for economic revival and town reconstruction, some modern architects aimed for the perfect single building, losing concern for the organic order of urban integrity under the slogan of functional supremacy [2], [3]. Modern cities suffered not only from energy problems [42] but also from fragmentation caused by isolated buildings, traffic infrastructures, and leftover spaces [48], gradually turning buildings into objects rather than the background of urban space, and creating the urban fabric crisis. Currently, the same scenario is emerging in China, where rapid urbanization has forced many historical districts with unique local characters to disappear [46], [52]. These include a lack of conceptual rigor and incomplete understanding of urban fabric and an ignorance of the deeper significance and history of specific urban space [24]. A lack of connection to the environmental context and the absence of people's sense of belonging forced the Chinese government to initiate smart growth policy as a new strategy for scientific and reasonable urbanization, including urban form optimization and urban space improvement at both macro and micro scales [30].

Previously, studies on urban fabric have been focusing on its conceptual definition [22], prototypical and spatial description [27], spatial and temporal evolution [9], [33], [50], and correlation with urban activities [23]. It is also argued that the visual aspect of urban space such as buildings, open space, and street scenery, could distinguish cities from others [39], indicating the possibility of a quantitative method to study urban fabric by considering the size, shape, form, and relative allocation as a whole [38]. So far, there are several computational methods and tools available for indirect urban fabric analysis, such as space syntax [13], [15], [16], Isovists analysis [5], [8], density-based quantitative analysis [18], [40], [41], and topological analysis based on data mining techniques [20]. However, most of the attempts are 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 [36].

Smart ages have prompted series development of information technologies, including Geographic Information System (GIS), Virtual and Augment Reality (VR & AR), Multi-agent simulation (MAS), and other new computational techniques, which have been used in the spatial analysis of urban studies [6], [7], [47], [53], providing a deeper understanding of urban structure and dynamics [33]. In this research, we provide a comprehensive computational method to investigate the urban fabric on a block scale taking Hankou as a case study where massive demolition and construction coincide with the rich hybridity of the urban context. Key shape indicators of the urban fabric are combined for a quantitative analysis of urban blocks with buildings to clarify their formal and hidden characteristics, with the help of GIS and statistical techniques. This case study is anticipated to provide a new perspective for urban fabric interpretation.

II. SELECTED CASE AND DATA PREPARATION

During a field investigation, some temporary shacks were found inside the urban blocks. The field investigation did not require any specific permission because it did not involve endangered or protected species. Modern cities influenced by colonial or concessional forces have been common since the 15th century [19]; these cities include Boston and New Delhi, both influenced by Great Britain; Mexico City, by Spain; Taipei, by the Netherlands; Ho Chi Ming City, by France; and Pyongyang, by Japan. Most of these cities were either newly established or dominated by one major foreign culture at one time, show different extents of urban fabric hybridity. In China, 16 cities successively set up concession areas, including Shanghai, Tianjin, Guangzhou, and Hankou. Most of these Chinese concession areas were occupied by several foreign forces, while Hankou, as an extreme, was influenced by as many as five major countries (Britain, Russia, France, Germany, and Japan) simultaneously. Mixed cultures and physical heritages laid the basis of the urban fabric hybridity. Moreover, Hankou is located at the center of Chinese economic geography, surrounded by Beijing, Shanghai, Guangzhou, and Chengdu within 1000 kilometers; it is the only city where the Yangtze River joins the Han River to form a west-east artery [4] and the Beijing-Guangzhou high-speed rail line serves as the north-south corridor, further facilitating the fusion of different cultures in China. The Hankou riverside area is a narrow linear area of approximately 4 kilometers and 218 hectares, bounded by some important urban corridors, such as Yanjiang Avenue, Zhongshan Avenue, Jianghan Road, and the second Yangtze

FIGURE 1. Location of Hankou and selected study area.

River Bridge (Fig. 1). Since 1861, five foreign countries consequently set up concession quarters in this area for better management of commercial affairs. Since then, this area has become the business and industrial center of the three towns as well as for China as a whole. Additionally, this area is the most important material and culture carrier of modern China, with innumerable historical buildings preserved from different cultures, such as banks, consulates, customs houses, guild houses, churches, clubs and other institutional buildings. Moreover, many traditional residential buildings and apartments are preserved, such as Li-fen (Fig. 2), which is a typical residential unit with both Chinese features and

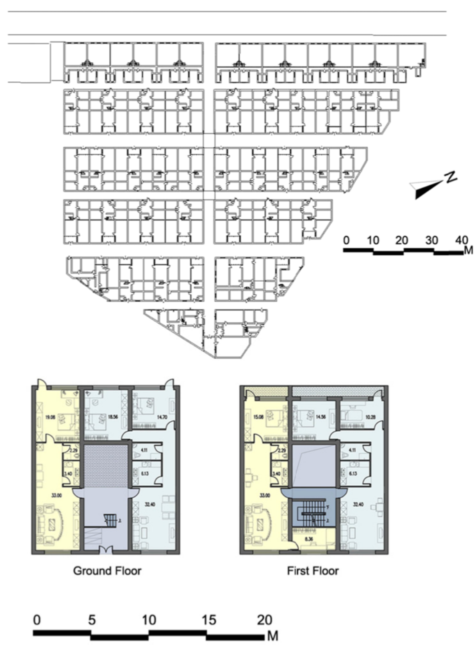

FIGURE 2. A typical Li-fen quarter and unit.

western construction. After the establishment of the People's Republic of China in 1949, the government redistributed these buildings to different holders through confiscation, levy, rent, or purchase. Due to the influx of outside populations, the buildings' condition deteriorated quickly and the original functions could no longer meet the city's basic needs; therefore, many new householders began to renovate these buildings by remodeling or constructing extensions. Additionally, the government began to demolish historical buildings within some plots to make way for new public buildings, factory dorms, and apartments. These two major forces changed the original urban fabric in this area. Therefore, this area features historical continuation and disruption, and could be an epitome of Chinese urbanization in the past century (Fig. 3).

FIGURE 3. Typical townscape of Hankou riverside area.

This study is based on a large amount of field investigation, and 83 urban blocks are selected for deep analysis. The data for this paper included map data for the Hankou riverside area in 2014, which comes from the local planning bureau. All of the maps are checked against the ground truth for land use, plot boundaries, and other existing conditions to find a proper match. During the field investigation, some temporary shacks were found inside the urban blocks. Most of these shacks were built simply and spontaneously by local residents. To alleviate these outliers and emphasize the main structure of the existing urban fabric, these shacks and similar buildings are purposely eliminated from our data, along with the buildings that had been demolished but were still shown on the map.

The method involves three main phases suggested by [51]: representation, analysis and description. The representation phase involves the preparation of the geometric data of urban blocks with building footprints and the selection of predefined shape indicators. The selected indicators 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. There is no perfect answer for indicator selection because perspectives may be different [34]. In our case, indicator selection mainly focuses on geometric, structural, and physical characteristics of the urban fabric, and multiple indicators are combined to represent different aspects of the urban fabric and produce an integrated overview [10].

III. DEFINITION OF URBAN FABRIC INDICATORS

Urban fabric reflects the morphological composition of physical elements within a certain area. Figure-ground analysis is usually used as a traditional method of understanding the urban fabric by regarding the building as an 'object' and space as the 'background,' but it is difficult to compare complex and similar building compositions without a precise corresponding description. Therefore, this paper attempts to integrate multiple normalized indicators to conduct a quantitative measurement of the urban fabric.

A. DENSITY

Slow growth and self-reparation tend to result in the old city center having a dense urban fabric, in which buildings and urban space are maintained at a human scale. Density could be regarded as uniform building coverage on a certain plot, reflecting the spatial contrast between figure and ground. To some degree, planners and architects could anticipate and differentiate specific urban forms based on density, as follows [41]:

$$Density = \frac{\sum S_i}{S_B} \tag{1}$$

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

B. COMPACTNESS

Compactness is used to describe the allocation and spatial distribution of buildings within blocks, and complements density. The formula for compactness is based on the gravity model [49], which is used to measure urban sprawl and agglomeration as follows:

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

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 [54]. The calculation is processed on a raster; therefore, the resolution of the raster should be uniformed before-hand.

$$Compactness = \frac{\mathrm{C}}{\mathrm{C}'} \tag{3}$$

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

C. VARIATION

According to Gestalt psychology, human cognitive processes used to follow a grouping integrity which featured proximity, similarity, good continuation, closure, symmetry, and parallelism [25]. According to this principle, the variation in building footprints could be used to show a certain sense of rhythm when the footprints are close to each other and share a similar size. The coefficient of variation is defined as the ratio of the standard deviation to the mean [17] as:

$$Variance = \frac{\frac{\sum\sqrt{(S_i-\bar{S})}}{(N-1)}}{\bar{S}} \tag{4}$$

where is S_i the footprint size of each building, and S_{mean} is the mean of building footprint size values, and N is the number of buildings.

D. FRAGMENT

Gibberd and Frederick [22] noted that fineness and homogeneity are important for describing urban fabrics. A single building and a group of buildings might present different configurations under similar density conditions. Therefore, the complexity of the urban fabric is relevant to the number of buildings and their composition [21]. Complex urban fabrics tend to be fragmented. 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 indicator has been widely used in landscape ecological research [14]. Therefore, urban fabric fragmentation could be defined as follows:

$$Fragment = 1 - \frac{4\sqrt{S_i}}{\mathrm{P}} \tag{5}$$

where S_i is the footprint coverage of each building within an urban block, and P is the perimeter of tested patch composed of buildings.

E. COHESION

Cohesion is a complementary indicator to fragmentation and is used to describe how many buildings agglomerate together. First, fragmentation is calculated. Second, the building footprint shapes are aggregated into patches if they are within a pre-defined threshold, and fragmentation is calculated again. Third, cohesion is calculated as the absolute value of the difference, as follows:

$$\text{Cohesion} = \left|F - F'\right| \tag{6}$$

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

IV. DESCRIPTIVE ANALYSIS OF THE DATA DISTRIBUTION

Five indicators are calculated for the 83 blocks. Fig. 4 provides an overview of the data distribution. Coverage, compactness, and variation seem to be normally distributed, according to the histograms. For these three indicators, the mean value is located around the symmetrical axis of the normal curve, while the other values gradually slope down from the mean to both curve tails, indicating the richness of the data set from low to high values. The urban fabric is well distributed within these three indicators. However, when we look at fragmentation and cohesion values, the distribution tends to be more skewed. For fragmentation, the distribution is skewed to the right side, and most values are concentrated at high values of approximately 0.9, indicating a high level of fragmentation; in other words, the urban fabric is composed of fine-grained buildings that are not adjacent to each other. Meanwhile, the cohesion values are skewed to the left and concentrated at low values of approximately 0.1, which indicates the same situation as that of the fragmentation values. Therefore, we have a general picture of the urban fabric of the Hankou riverside area, where many tiny voids might exist inside the blocks to form a very complex urban fabric.

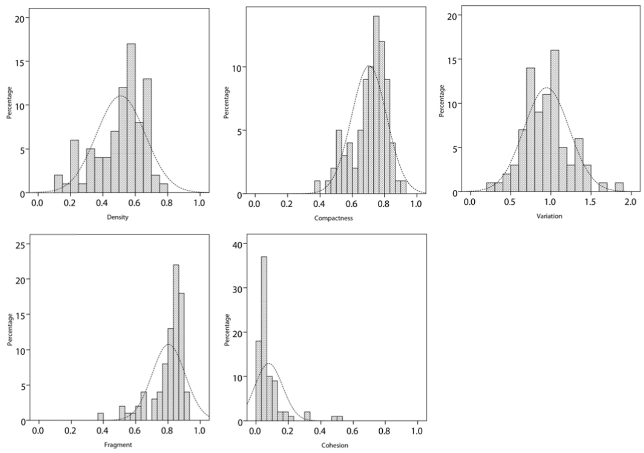

FIGURE 4. Histogram of the fabric indicators.

In addition to these five indicators, the number of buildings is also included in the correlation coefficient matrix to investigate the filling within urban blocks. Pearson's coefficient is used for the linear test and Spearman's coefficient is used for the monotonic test (Tab. 1 and Tab. 2). Both coefficients are compared with a scatter plot (Fig. 5) to determine if these indicators are correlated.

TABLE 1. Pearson coefficient matrix of selected indicators.

Pearson Coefficient	Density	Fragment	Variation	Compactness	Cohesion	Building Number
Density	1					
Fragment	0.273*	1				
Variation	0.294**	-0.331**	1			
Compactness	0.716**	0.055	0.213	1		
Cohesion	0.134	-0.251*	0.007	0.371**	1	
Building Number	0.258*	0.751**	0.384**	0.074	-0.341**	1

TABLE 2. Spearman coefficient matrix of selected indicators.

Spearman Coefficient	Density	Fragment	Variation	Compactness	Cohesion	Building Number
Density	1					
Fragment	0.222*	1				
Variation	0.222*	-0.324**	1			
Compactness	0.713**	0.023	0.150	1		
Cohesion	0.293**	-0.277*	0.146	0.360**	1	
Building Number	0.247*	0.978**	0.387**	0.058	-0.283**	1

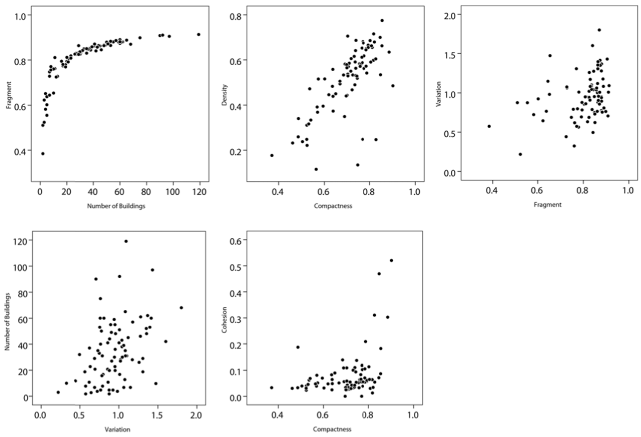

FIGURE 5. Correlation among the fabric indicators.

The correlation could be classified as none (under 0.2), weak (0.3 to 0.4), medium (0.4 to 0.6), or high (above 0.6), based on the coefficient value [11]. Scatter plots should be used to assist in determining whether two variables are correlated. As the result, four pairs of indicators turn out to be correlated to a certain degree, and two of them are highly correlated. Among these indicators, fragmentation and the number of buildings present very high nonlinear correlation, with a value of 0.978 for Spearman's coefficient, at the 0.99 confidence level. Looking at its scatter plot, the fragmentation value rises rapidly until the number of buildings increases to approximately 40. The fragment value then starts to stabilize, increasing slowly because buildings tend to cover the whole block at this level. Additionally, density and compactness present a high linear correlation, with Spearman's coefficient and Pearson's coefficient being very similar, at values of approximately 0.71. The scatter plot shows that most correlation happens around high values, indicating the potential bounding function of urban blocks. In this case, due to the existence of block boundaries and urban roads, new buildings tend to be constructed close to the old ones. Therefore, it is easier to form a compact urban fabric.

V. CLASSIFICATION BASED ON DENSITY

In this case, the study area is located at core of the Hankou metropolitan area, where it is easier to find higher densities Therefore, density could be regarded as a baseline for investigating the other four indicators to provide a deeper understanding of the urban fabric. According to [28] and [29], a density value of 0.5 could be regarded as the threshold for high density. Of the 83 urban blocks in this case, 54 are above this standard, accounting for 64% of all samples, and further demonstrating the fact that Hankou's riverside area could be regarded as a high-density area. Figure 4(a) shows that the highest density blocks are within the Britain quarter, Russian quarter, and French quarter to the southwest end, and the density generally decreases toward the northeast end until the Japanese quarter, which has the lowest density. The highest density among all blocks is 0.775 and the lowest is 0.115.

From the above analysis, we have a preliminary sense that density values are normally distributed among the 83 blocks. The Kolmogorov-Smirnov (KS) test is used to determine if density values fit a normal distribution by measuring the goodness-of-fit between the empirical distribution of a set of n observations and a given continuous probability distribution. Given n ordered values, x1<x2…<xn, the test formula was proposed by [26] as follows:

$$T = \sup_x \left| F^*(x) - F_n(x) \right| \tag{7}$$

where $F^*(x)$ is the hypothesized distribution function, whereas $F_n(x)$ is the empirical distribution function (EDF) estimated based on the random sample. In the KS test of normality, $F^*(x)$ is taken to be a normal distribution with a known mean and standard deviation. The KS test statistic is used for testing,

H_0: $F(x) = F^*(x)$ for all x from $-\infty$ to ∞ (specific distribution).

H_1: $F(x) \neq F^*(x)$ for at least one value of x not following specific distribution.

The test result turns out to be significant under the 0.95 confidence level, and the p-value is 0.081, which is higher than 0.05. Therefore, we can further confirm the previous hypothesis that density values are normally distributed, with mean $\mu = 0.51$ and standard deviation $\sigma = 0.15$.

According to the normal distribution law, 68% of values are contained within a standard deviation. Therefore, we can split blocks into three density groups according to the density value: low (under 0.36), medium ($0.36 < \mu \pm \sigma < 0.66$), and high (above 0.66). Seventeen blocks are selected as low-density samples, accounting for 20% of the total. Fourteen blocks are selected as medium-density samples, accounting for 17% of the total. Finally, 12 blocks are selected as high-density samples, accounting for 14.5% of the total.

Thereafter, all five indicators should be divided by their means to standardize deviations, using the following function:

$$X' = \frac{X}{\overline{X}} \tag{8}$$

Where X is original value and $\overline{X}$ is the mean.

Fig. 6 indicates the gradient distribution of all five indicators for the study area.

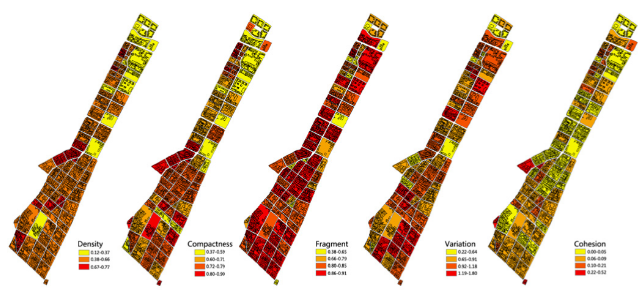

FIGURE 6. Gradient map of different indicators.

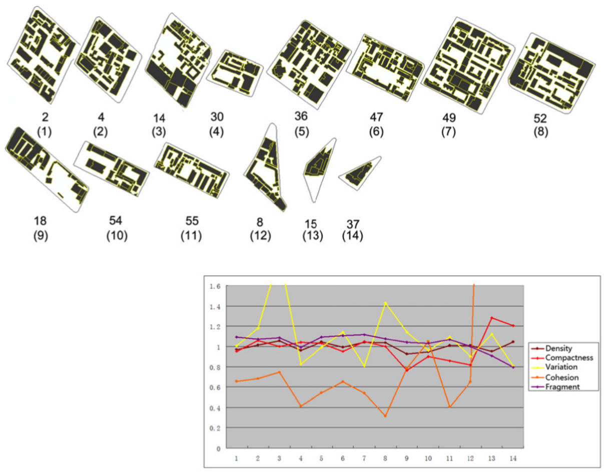

FIGURE 7. Blocks of medium density and chart of selected indicators.

VI. RESULT OF MULTI-INDICATOR ANALYSIS

For the medium density blocks (Fig. 7), their fragmentation values are smoothly distributed at approximately 1.1, which is slightly higher than the average level, indicating moderate complexity for the patch shape, with quite a few buildings congesting the block. Some blocks with small sizes, such as Blocks #30, #8, #15, and #37, tend to have low levels of fragmentation because there are fewer buildings in those blocks. There are no clear peaks or valleys for fragmentation values, except for Block #37, which has a very low fragmentation value because a monolithic, triangular residential complex occupies the entire block. Differentiation among these blocks starts to emerge when we take compactness into account. The first row of block samples in Figure 5 could be regarded as the same group because their compactness values are stable and near the mean. The compactness values of the second row of samples start to fluctuate, with Blocks #12 and #18 at the bottom and Block #15 at the peak. Although containing a solid quarter on its northwest end, the compactness value of Block #18 is undermined by its narrow shape as well as the quarter with large open spaces on the southeast end, where the a small public art gallery is located. Unfortunately, the open space is mainly used as a parking lot instead of the public activities for which it was planned. Block #8 contains some important bank buildings, such as the Zhejiang Commercial Bank and Canton Bank, which have existed since the early 1920s, because it is close to the business center where Jianghan Road and Zhongshan Avenue intersect. Most buildings are located along the block boundary for better connection to the flow of traffic, leaving a courtyard in the center. Therefore, the compactness value of Block #8 is low, due to the loose building allocation and triangular block shape. So far, most buildings have been converted to photographic studios, and the court yard is mainly used as an outdoor shooting location and logistics lot. Blocks #15 and #37 are very similar, with the highest compactness value and similar shape because both blocks are occupied by monolithic building complexes, even though their other indicators are different. The building in Block #15 was initially the KinCheng Bank and was remodeled into the City Art Gallery after 2005. Variation values fluctuate significantly around the mean with seemingly regular periodicity. Building footprints are most evenly distributed within Blocks #30 and #49, which are major residential quarters, and most unevenly distributed within Block #14, where the Pinghe package factory has been located since 1905. This factory is composed of six closely connected solids, which account for one third of the entire block, while the others are small, plain buildings less than 20 years old. Cohesion values also present a significant fluctuation, but are mostly below or near the mean, except for Blocks #15 and #37, which could be considered fully agglomerated as monolithic figures. Block #30 is special because two countries (the US and Russia) simultaneously decided to build consulate buildings in the same block in the late 19th century. Therefore, most buildings in this block leave some distance from each other, resulting in a relatively low cohesion value.

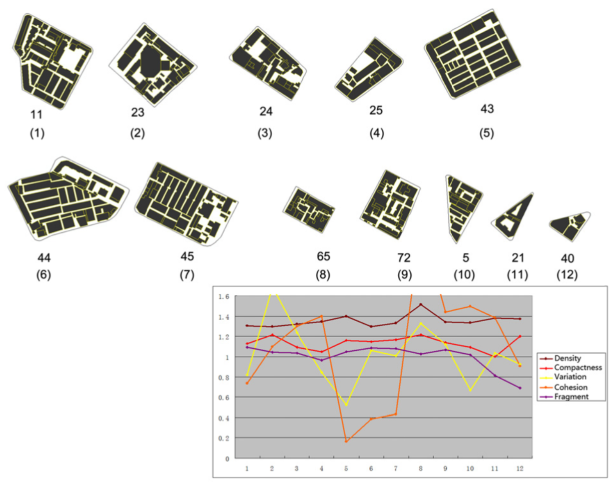

FIGURE 8. Blocks of high density and chart of selected indicators.

For those high-density blocks (Fig. 8), most of their fragmentation values are also smoothly distributed and slightly above the average level, presenting no significant difference from the fragmentation values of medium-density blocks, except for Blocks #21 and #40. These two blocks are smaller than other high-density samples and difficult to categorize, with a very complex urban fabric in limited space. Block #21 is the famous Russian Mansion, which was initially the largest townhouse apartment when it was built in 1909. The triangular block is split into two parts, with buildings on the periphery and courtyard in the middle, presenting the lowest compactness value in this group of blocks. Another block with low compactness value is Block #25, which features a flat trapezoid shape with a void to the north, and is famous for being the historical site of the Chinese Communist Party Congress in 1927. The compactness values of other blocks stabilize above the mean, especially when we compare Blocks #43, #44, and #45. Block #23 is exceptional because a gigantic stadium is located in the middle, making the urban fabric more centralized and diverse. Block #40 presents high compactness because it is mainly composed of large-scale entities, such as the old cinema and community library. In Block #65, intensive building agglomeration within a square block leads to a high compactness value. Variation values fluctuate even more significantly around the mean than do compactness values. Block #23 stands out again because the stadium, as a landmark, creates a conspicuous fabric mutation from its surroundings. The lowest variation happens in Block #43, which is occupied by Li-fen (Sande Li, Gongde Li, and Hongwei Li), a typical early modern Chinese residence blended with western construction and features. Li-fen usually consists of two components. In the middle, dozens of uniformed two-story residences are organized in a gridiron layout and shaped like a military camp site, while the surroundings are mixed-use or commercial. Around the 1930s, more than 200 Li-fen quarters created a remarkable feature for the urban fabric of the Hankou riverside area, but less than 100 were left by 2007, and more are disappearing. Spontaneous construction and encroachment on public space intensify the level of variation and leave less homogeneous urban fabric at the price of dismantling historical quarters. This can be confirmed by the cohesion values, which are mostly far above the mean, and only Blocks #43, #44, and #45 still remain somewhat intact. The highest cohesion level occurs in Block #65 in the Japanese quarter. Privately built one-story or two-story buildings account for a majority of this block, which is only a quarter as large as regular blocks. These plain buildings are mainly rented to neighboring small, local businesses and the market has been stable for many years. The only voids are three passages radiating from the center to satisfy basic daily needs.

Most of the low-density blocks are within the Japanese quarter, which was the latest concession area and has relatively less development (Fig. 9). All of the indicators in this group present very intensive fluctuation, mostly below their means, indicating a significant change and diversity of the urban fabric. Quite a few blocks have been demolished or replaced with office buildings, hotels, and other institutional buildings in the urban regeneration movement since the 1990s, resulting in a decrease in the spatial richness of the urban fabric. In Block #51, most of the original urban fabric has been torn down, with the exception of the national congress administration building in Wuhan. For Blocks #76 and #81, monolithic commercial or office buildings with simple profiles tend to be constructed with large parking lots around them, creating a different urban fabric in this area. For the compactness values, most blocks are noticeably below the mean, except for Block #16 and two other newly developed blocks. In Block #16, a very unique residence complex named Xian'an Fang is composed of three Li-fen quarters, which are obliquely crossed. This quarter was built in 1915 as one of the biggest Li-fen at that time. Block #46 was initially dedicated to the German consulate but so far is the location of the city municipal office. It is mainly occupied by small, dispersed buildings around a huge central courtyard with good environmental quality, leading to the lowest compactness not only in this group but also among all 83 blocks in this study. However, this block does not function like a public living room because it is only accessible to a few inner users. The variation and cohesion values are mostly below the mean, although they are even more unstable than the low- and medium-density samples, indicating a highly mixed building typology and dispersion allocation. Block #59 is an example where many different types of buildings, such as old Japanese dorms, high-rise tower residences, tower residences with annexes on the ground, and hotels, are mixed side by side, creating a unique mosaic of urban fabrics in this area.

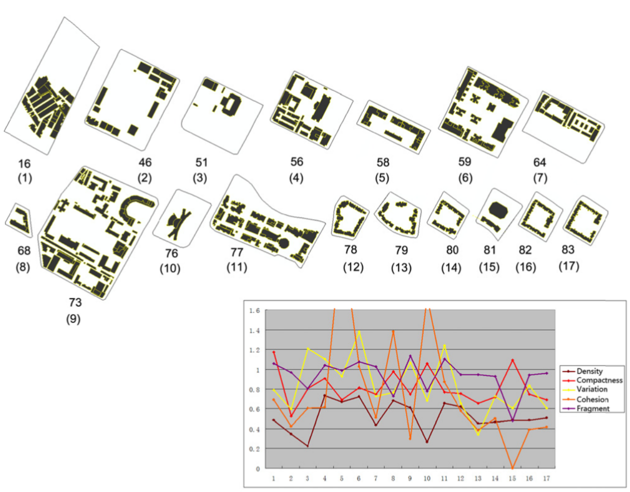

FIGURE 9. Blocks of low density and chart of selected indicators.

VII. DISCUSSION AND CONCLUSION

This paper examines urban fabric diversity using five quantitative indicators, with the Hankou riverside area as a mirror for Chinese urbanization in the past century. By analyzing the value distribution pattern, the correlation among values, and the relationship between indicator values and spatial quality, we are able to depict the urban fabric in a more comprehensive manner. Blocks were split into three groups from low to high density, and further analysis has been conducted within the three groups; the results show that each group presents a specific value range for these indicators. (1) Medium-density blocks more often present a clear and uniform urban fabric, with the three major indicators closely distributed around the mean, although variation and cohesion exist with slight fluctuations. Most medium-density blocks are able to inherit the features of the original urban fabric without too much intervention and fit into the context well. (2) High-density blocks are barely maintained intact, but the indicators seem more dispersed from each other above the mean. For these blocks, extra backyard work without permits might encroach on public space and threaten the original urban fabric. (3) Low-density blocks face more challenges to maintaining a coherent urban fabric, with all indicators fluctuating significantly. Historical heritage is not as well-preserved in these blocks, due to arbitrary demolitions and massive development projects. Moreover, the potential deterioration of the urban fabric also implies an undeniable turning period in Chinese urbanization, both physically and socially [4], with a change from a society attached to the land to one that is very much on the move [43].

Urban fabric is a valuable representation of urban civilization and is as important as other city data in the smart-information age, reflecting on the behavior of humans in their daily life [44]. Therefore, we should pay more attention to effective interpretation and reasonable intervention in order to build a strong foundation for positive and healthy living patterns, especially when China tends to be saturated with incremental planning [37]. Through this research, we found that moderate urban density is necessary not only for the emergence of urban fabric but also for a sustainable urban life. A certain number of small-scale buildings organized in a preferable manner, such as Li-fen or other quarters with historical heritages, tends to form more a harmonious urban fabric with more livable richness inside than those newly developed quarters with monolithic buildings. This might explain why the Hankou riverside area could still remain attractive and identifiable after suffering so much during the war, civil revolution, and massive urbanization of the past century. The sustainable development of a city should attach great importance to the protection and continuation of local characteristics of integrity and authenticity through multi-index research, more in-depth interpretation, and more suitable strategies which adapt to the urban development.

Through the analysis described in this paper, it has been possible to identify the hybridity of urban fabric at the block scale using a series of physical properties. Although urbanization is driven by numerous factors from the environment, economics, and culture, these factors are eventually reflected in the physical environment, which exerts the most direct influence on daily life and therefore deserves more attention in long-term planning. The results of this study show that the diversity of urban fabric hybridity plays a major role in anchoring the urban context, which is often ignored in many Chinese cities with rapid urbanization.

Additionally, along with the rapid development of transportation technology and integrated globalization, human mobility has gradually strengthened. In the coming centuries, a large number of immigrants from different racial and cultural backgrounds will increase the hybridity of the urban fabric by contributing more architecture with unique characteristics. By investigating the hybridity phenomenon of the urban fabric, this paper also expects to stimulate more effective planning strategies for cities with hybrid urban fabrics. In future, 3D virtual reality geographical information system may provide an intuitive approach for smart city assessment [55]–[57].

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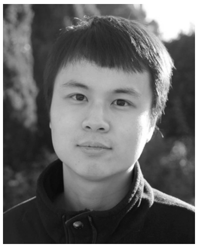

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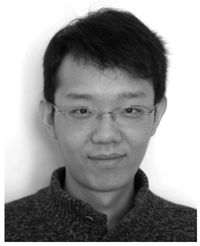

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