

Article

Delineating and Characterizing the Metropolitan Fringe Area of Shanghai—A Spatial Morphology Perspective

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Abstract: The metropolitan fringe area is of great significance to a city's future growth. However, relatively little attention has been paid to delineating and characterizing the metropolitan fringe area from a spatial morphology perspective, which contributes to the planning and design of metropolitan fringe areas. Therefore, the aim of this study is to develop a morphology-based method to delineate the metropolitan fringe area and investigate the characteristics of its spatial morphology. Drawing upon a large-scale dataset on the spatial morphology of Shanghai, this study finds that the metropolitan fringe area is generally circular in shape and is dominated by residential, industrial, agricultural and forestry land. The metropolitan fringe area accounts for 24.65% of the total area of Shanghai and is mainly located between its outer ring and suburban ring areas. The distributions of spatial characteristics of the metropolitan fringe area suggest that the area has a relatively lower level in terms of building height, building density, and development intensity. Furthermore, the metropolitan fringe area of Shanghai contains five key spatial elements, including residential and industrial clusters, shadow spaces accompanying clusters, corridor lines, green wedges, and surfaces. The interaction of the five spatial elements lays the foundation for the prototype of the spatial structure of the metropolitan fringe area of Shanghai, which is of great significance to understanding the heterogeneity within the metropolitan fringe area in terms of the distribution of spatial morphological characteristics. Such heterogeneity also needs to be considered in the planning and design of the metropolitan fringe area.

Keywords: metropolitan fringe area; urban morphology; spatial prototype; morphological heterogeneity; Shanghai



Citation: Xiong, W.; Yang, J. Delineating and Characterizing the Metropolitan Fringe Area of Shanghai—A Spatial Morphology Perspective. *Land* **2023**, *12*, 2086. <https://doi.org/10.3390/land12122086>

Academic Editors: Mengqiu Cao, Hongsheng Chen and Yang Xiao

Received: 12 October 2023
Revised: 14 November 2023
Accepted: 14 November 2023
Published: 21 November 2023



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1. Introduction

In many areas of the world, the process of rapid urbanization has made the boundaries between urban and rural areas become increasingly blurred, leading to the emergence of vast areas that are neither urban nor rural, and they have been mainly characterized by discontinuous and low-density developments [1,2]. Such areas have commonly been called metropolitan fringe areas [3], peri-urban areas [4,5], or urban-rural fringe areas [6] in the extant literature on urbanization. However, no matter which concepts are used, metropolitan fringe areas usually refer to a transitional zone between urban and rural areas [7,8]. Under the influence of rapid urbanization, these areas are where the processes of urbanization and industrialization firstly occur, thus making them the most sensitive and rapidly changing regional entities during urban expansion. In fact, metropolitan fringe areas are not only a spatial carrier for the expansion of urban development but are also an exchange and distribution center for materials, energy, and information between urban and rural areas [9]. Therefore, the development of metropolitan fringe areas has become an important part of urban spatial development and a key factor reflecting the

level of a city's high-quality development over the last decades. The Report on Key Tasks for New Urbanization and Urban–Rural Integration Development put emphasis on the optimization of the spatial layout and morphology of urbanization areas. Also, under the urban double–repair policy, the ecological restoration of the urban fringe area is emphasized, but its specific form and land use are less considered.

The metropolitan fringe area has been constantly changing during the process of rapid urbanization. Therefore, how to define and delineate metropolitan fringe areas has always remained a hot research topic among scholars. In earlier days, metropolitan fringe areas were mainly defined and discussed based on experience. For instance, Pryor defines metropolitan fringe areas as “a zone of change in land use, social and demographic characteristics, located in a land use conversion area between contiguous built-up areas and suburbs and a pure agricultural hinterland almost completely devoid of non-agricultural housing, non-agricultural occupation and non-agricultural land use” [10]. More recently, metropolitan fringe areas have been delineated in a more quantitative and non-subjective way. Within this line of the literature, existing studies have drawn upon a variety of datasets such as remote sensing images [11,12], nighttime lights [13–15], points of interest (POI) [16], or a combination of some of these data sources [17–20]. Importantly, no matter which types of data have been used to delineate the metropolitan fringe area, the rationales behind these quantitative delineation methods are generally similar. That is, the metropolitan fringe areas differ significantly from purely urban or rural areas in terms of land use properties and human activity characteristics, both of which have profound influence on spatial morphology. In fact, due to the discrepancy in development mode and function assumption, the construction patterns of buildings in metropolitan fringe areas tend to be more complicated, leading to differences in height, density, and intensity.

From the perspective of spatial morphology, metropolitan fringe areas are also distinctive in terms of the height, density, and intensity of developments, and they have been generally conceived as areas with a relatively lower level of development intensity and building density. With an increasing demand for the planning and design of metropolitan fringe areas, it becomes imperative to obtain a better understanding of the morphological characteristics of metropolitan fringe areas. Nonetheless, relatively little attention has been paid to delineating and characterizing metropolitan fringe areas by focusing on the differences in spatial morphology among urban, peri-urban, and rural areas. In fact, the traditional prototype theories of urban spatial structure have already pointed out that a city develops relatively uniformly in all directions, and its development process is therefore usually characterized by an expansion from core to periphery [21]. This process of urban expansion typically results in the formation of a near-circular concentric layout of a city. In this sense, spatial morphology indicators including the height, density, and intensity of developments would be similar to other types of indicators such as population density and land use, which generally decline from a city's inner ring to the outer ring. However, while many studies have observed such a declining process in terms of population density and nighttime lights, we still know relatively little about the precise distribution patterns of spatial morphology from urban to rural areas, let alone using a morphology-based method to delineate metropolitan fringe areas. Notably, a recent study by Péntzes et al. has investigated the distribution patterns of built-up intensity (represented by the number of buildings) in a central European city in addition to the changes in its population density [22].

In light of the above-mentioned research gap, this paper takes Shanghai as an example, aiming to delineate its metropolitan fringe areas from the perspective of spatial morphology and investigate the distribution patterns of spatial morphological characteristics. By drawing upon a large-scale and block-level dataset on the height, density, and intensity of developments across Shanghai City, we construct a morphology-based method to delineate its metropolitan fringe areas and investigate the characteristics of spatial morphology of these areas. In doing so, we aim to contribute to the literature by providing an alternative perspective from which to delineate and characterize metropolitan fringe areas, which

would enrich and broaden our understanding of metropolitan fringe areas from the perspective of spatial morphology. Moreover, this paper contributes to the literature on spatial morphology, which has often focused on analyses of morphological characteristics of urban core areas while ignoring the potential morphological heterogeneity within metropolitan fringe areas.

The remainder of this paper is structured as follows. Section 2 reviews the existing literature on the delineation of metropolitan fringe areas and the analysis of their multi-faceted characteristics. Section 3 describes the data and methods that have been used in this study. Section 4 describes the delineation and characteristics of Shanghai's metropolitan fringe areas based on spatial morphology data. Section 5 discusses the empirical results and their policy implications. Section 6 concludes.

2. Literature Review

2.1. The Functional and Morphological Approaches to Delineating Metropolitan Fringe Areas

Research on the metropolitan fringe can be traced back to the end of the 19th century and the beginning of the 20th century. During this period, cities in Western countries emerged due to rapid development, leading to a series of land use, and social and ecological problems. Under the context of evolutionary urbanism, the metropolitan fringe is no longer simply considered the contradiction between man and nature but is part of the community network structure [23,24]. This actually enriches environmental landscape research content and promotes its sustainable development.

The delineation of the metropolitan fringe area is closely related to its definition, which, however, has not reached a consensus in the existing literature. Therefore, a variety of delineation methods have been proposed by scholars, which can be classified as either functional or morphological approaches. Functional approaches adopted in earlier studies have been mainly qualitative and experience-based. For instance, Friedman et al. define a city's metropolitan fringe area as an area of approximately 50 km around the city, according to the extent of people's daily commuting. More specifically, the inner fringe area is about 10–15 km around the city, while the outer fringe area is 25–50 km around the city [25]. Lesage et al. use the location of new houses under construction in suburban and rural areas as an anchor point for the identification of metropolitan fringe areas. Specifically, this approach defines the metropolitan fringe area as an area that has been driven by new urban construction projects. However, the scope of the metropolitan fringe area delineated through this approach is not a well-defined boundary but a relatively ambiguous space [26].

Due to the development of geo-information technologies and the increasing availability of different types of data, recent studies have aimed to adopt more quantitative and scientific approaches by drawing upon a variety of datasets such as nighttime lights, remote sensing images, population density, points of interest (POI), etc. However, most studies have focused on the functional characteristics when delineating the metropolitan fringe areas. For instance, in the context of rapid urbanization in China, some scholars have drawn upon nighttime light data to delineate the metropolitan fringe areas of Beijing [13], Wuhan [14], and Nanjing [15], respectively. Since POI data contain both spatial and socio-economic attributes and can reflect industrial structure, some studies have delineated metropolitan fringe areas based on POI data. For instance, Dong et al. propose a delineation method that considers the metropolitan fringe area as the distinction region of the service and manufacturing industry extending outward from the inside of the city, which can be reflected by the POI density of the respective industries [16].

More recently, a combination of different sources of datasets has been used in the delineation of metropolitan fringe areas. Therefore, some studies have incorporated morphological indicators such as land use mix in their function-based identification approach. For example, Li et al. developed a fringe extraction model of small- and medium-sized urban areas by using a set of data sources including high-resolution imagery from the GF-2 satellite, the WorldPop dataset, and POI [17]. Shi et al. stress that the metropolitan fringe area should be identified from a multi-dimensional perspective and propose an

identification index system including indicators such as discontinuous land use, increasing population density, and fluctuating land use efficiency [18]. In addition to the increasing diversity of datasets that have been used to delineate the metropolitan fringe area, some studies have developed more complex mathematical methods by using machine learning-related algorithms. For instance, Pagliacci introduces a fuzzy rurality indicator, which enhances urban–rural classification by capturing multidimensional nuances in factors like agriculture, population density, and land use characteristics [27]. Liu et al. utilize deep learning techniques to construct a city–edge determination method based on multi-source datasets including remote sensing imagery, population data, and POI data, which effectively divides Guangzhou into core, edge, and outer regions [19]. Sun et al. use the neural network models to identify the metropolitan fringe area with a particular focus on the significant influences of socio-economic indicators, such as nighttime light intensity, on the delineation results [28].

Overall, we can see that existing studies have achieved some remarkable progress in the aspects of the datasets and methods that have been used to delineate the metropolitan fringe area. However, existing studies have mainly adopted a functional approach to delineating metropolitan fringe areas, while relatively little attention has been paid to defining and delineating the metropolitan fringe area from the perspective of spatial morphology. In fact, we still know relatively little about the distribution laws of spatial morphology indicators (e.g., the height, density, and intensity of developments) from urban to rural areas.

2.2. *The Multi-Faceted Characteristics of Metropolitan Fringe Areas*

The characteristics of the metropolitan fringe area have been analyzed from multiple perspectives, such as land cover change, ecological environmental dynamics, population density, travel behavior, etc. Obviously, most of the characteristics that have been analyzed in the literature reflect the functional perspective of metropolitan fringe areas. In fact, some indicators representing the characteristics of the metropolitan fringe area have also been used in the function-based identification approach. Specifically, the characteristics of land cover change in the metropolitan fringe area have been commonly investigated within the literature. For instance, Bittner and Sofer (YEAR) investigate land use changes in the metropolitan fringe areas in Israel and identify some specific trends such as agricultural specialization, intensified land use, and expanded built structures [29]. Ding and Chen analyze the localized climate changes and spatial development patterns of high-rise residential areas in the metropolitan fringe area of Wuhan [30]. Wang et al. observe that there is significant spatio-temporal heterogeneity in land use functions in the metropolitan fringe area of Shanghai, which has been driven by human preferences and policies and suggests the need for function-based zoning [31]. Chiaffarelli et al. investigate peri-urban landscape features near Milan and identify floristic–vegetational deterioration due to anthropic disturbances [32]. Deng et al. analyze the spatio-temporal characteristics of construction land use change in Shenzhen’s metropolitan fringe area from 2000 to 2020 and explore how the changes in construction land use have been influenced by a variety of factors including population density, lighting index, and distance to the highway [33].

In terms of the characteristics of ecological environment dynamics, some studies have investigated how the ecologically sustainable development of the metropolitan fringe area has been affected by relevant factors. For instance, Kato analyzed the causal relationship between walkability and the Ecological Footprint to Biocapacity (EF/BC) ratio of each residential cluster in the metropolitan fringe area of Osaka, finding that walkability is negatively associated with the EF/BC ratio in the sprawl cluster yet positively affects the EF/BC ratio in the old new-town cluster [34]. Cui et al. take the metropolitan fringe area of the Tongzhou District of Beijing as an example to quantitatively analyze its landscape pattern. They find that the metropolitan fringe area of Tongzhou has been characterized by excessive fragmentation of green patches of small sizes, and they propose that the

construction of green corridors could be an effective way to protect biodiversity and solve urban ecological problems [35].

The metropolitan fringe area is also distinctive from urban or rural areas in terms of population distribution, which has drawn the attention of some scholars. For instance, on the basis of Reid Ewing's "3D" elements of the built environment, Dr. Robert Cervero proposed the "5D" elements version, which includes density, diversity, design, distance to transit, and destination accessibility [36]. This is generally accepted as the main measurement basis. Long et al. follow the "5D" evaluation indexes in the metropolitan fringe area of Wuhan to investigate the relationship between the population and the built environment [37]. Zhang and Zhang investigate the spatial and scale distribution characteristics of rural settlements in the metropolitan fringe area of Nanjing and find that the distribution of rural settlements has been affected by factors such as terrain, river system, traffic, culture, and policy [38]. Han et al. analyze the spatial characteristics of informal settlements in the metropolitan fringe area of Seoul, showing that the total area of informal settlements has decreased and the locations of these informal settlements have shifted from the urban core to the fringe area [39].

Last but not least, as the transitional region between the urban center and the fringe area, various flow factors are frequent in the metropolitan fringe area, especially people flow. So, some studies have focused on travel behaviors, aiming to investigate the influence of travelers' behavior on spatial connection. For instance, Millward and Spinney analyze people's travel behaviors across the metropolitan fringe area of Halifax, Nova Scotia, and discover significant inter-zonal differences with progressive urban-to-rural gradients in most travel variables but without a clear city-country divide [40]. Zhao and Wan investigate the travel burdens in Beijing's metropolitan fringe area, finding that this area is characterized by higher travel time and cost, limited job opportunities, and higher car ownership [41].

Although there is no consistent definition, various qualitative to quantitative delineation approaches have been proposed, most of which are from the functional perspective. To fill this research gap, this paper tries to define and delineate the metropolitan fringe area using the spatial morphological methodology. On the other hand, we can see that the multi-faceted characteristics of the metropolitan fringe area have been analyzed extensively in the literature, including land cover change, ecological environmental dynamics, population density, travel behavior, etc. Actually, the morphological characteristics of the metropolitan fringe area have remained largely under-explored, especially in terms of the height, density, and intensity of developments. Though the metropolitan fringe area has been commonly considered a transitional zone with discontinuous and low-density development, it is worth investigating the distribution patterns of morphological characteristics to reveal the potential heterogeneity within the metropolitan fringe area.

3. Case Study and Methods

3.1. Study Area

The study area of this research is the administrative area of Shanghai, excluding the Chongming District, the Changxing Township, and the Hengsha Township, which are separate islands and are usually not considered in relevant studies (Figure 1). This study area covers an area of about 6540 square kilometers and includes 15 districts. Within this area, the central urban area of Shanghai is enclosed by the expressway of Shanghai's outer ring road, while the area between its outer ring road and the administrative boundary could be considered as where both the metropolitan fringe area and the rural area of Shanghai are roughly located.



Figure 1. The study area of this research.

Shanghai is a suitable and representative case for investigating the development of its metropolitan fringe area for the following reasons. Under the influence of rapid urbanization, Shanghai has experienced remarkable urban expansion over the last two decades, creating vast areas of discontinuous and low-density developments outside the inner city. In 2021, Shanghai unveiled an ambitious plan to build five new towns in its suburbs that radiate out from its urban core areas from northwest to southeast. This plan has been regarded as part of the municipal government's efforts to optimize the development layout of its metropolitan fringe area. With the construction and development of the five new towns, the spatial morphology of Shanghai's metropolitan fringe area is expected to show some new characteristics. Thus, it is of great significance to investigate the current characteristics of the spatial morphology of its metropolitan fringe area to shed some light on their evolution trend in the future. In fact, some studies have already taken Shanghai as an example to investigate the development of its metropolitan fringe area, though relatively little attention has been paid to its spatial morphological characteristics [42,43].

3.2. Spatial Morphology Data

The data used for this paper are Shanghai spatial morphology data, which are not publicly available and were manually collected by the research group of the authors. Based on the complete and accurate vector topographic map of Shanghai's main city, the spatial morphology dataset is constructed after calibration, correction, and updating with a field investigation. It is worth mentioning that the database was first created in 2013 and then updated several times, so the latest version of this spatial morphology database was updated in 2020. To be specific, detailed information on buildings, land plots, blocks, and natural landscape environments is included in the spatial morphology data. The Shanghai database contains detailed geographical locations of 382,159 buildings, 25,399 land plots, and 11,354 blocks within the study area.

For each building, we have detailed information on its function, height, and floor area. By aggregating these building-level data to the block level, we can calculate three key indicators of the spatial morphology of each block, the expressions of which are given as follows:

$$Height_i = \frac{\sum_{k=1}^N height_{i,k}}{N} \tag{1}$$

$$Density_i = \frac{\sum_{k=1}^N floor_area_{i,k}}{area_i} \tag{2}$$

$$Intensity_i = \frac{\sum_{k=1}^N floor_area_{i,k} \times height_{i,k}}{area_i} \tag{3}$$

where $Height_i$, $Density_i$, and $Intensity_i$ represent the average building height, construction density, and plot ratio of each block i , respectively. $height_{i,k}$ and $floor_area_{i,k}$ represent the height and floor area of building k in block i , respectively. $area_i$ reflects the area of block i . N represents the total number of buildings in block i . Figure 2 shows the distribution patterns of the three indicators at the block level within the study area.

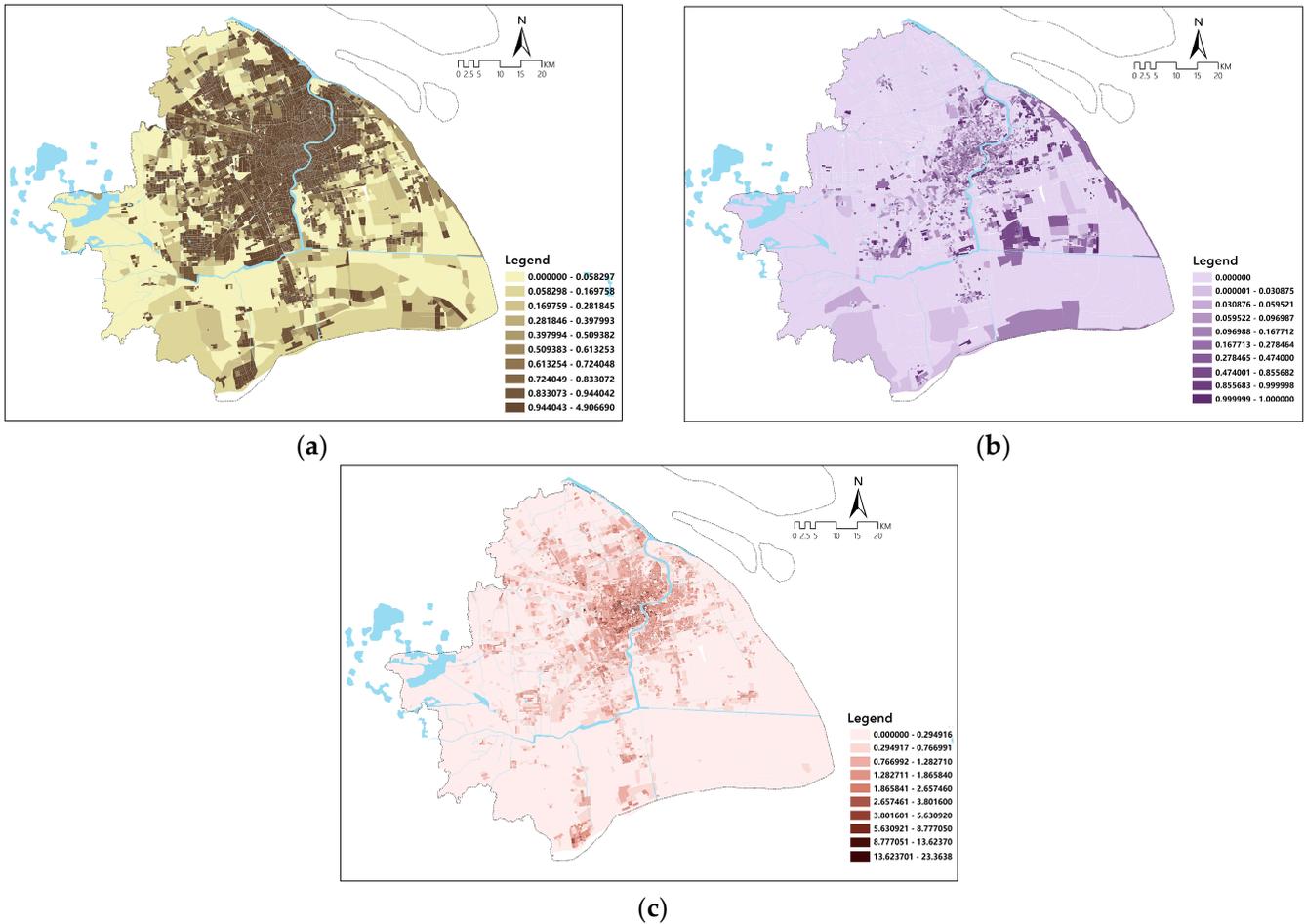


Figure 2. The distribution patterns of the three indicators at the block level within the study area. (a) Building height; (b) Building density; (c) Development intensity.

3.3. The Method to Delineate the Metropolitan Fringe Area

3.3.1. Principles of Constructing the Delineation Method

Before proceeding to construct the method to delineate the boundaries of Shanghai’s metropolitan fringe area, it is worth discussing some basic principles that should be borne

in mind when developing the delineation method. Specifically, we think the following four principles should be considered:

- Objectivity: the adopted method and the delineation process should be based mainly on mathematical or computer-generated calculations, thereby truly reflecting the rule of spatial distribution and reducing the bias of the empirical value;
- Simplicity: the delineation process should be simple and clear, and can be explained by quantitative detection or qualitative evaluation;
- Universality: the method should be applicable to delineating metropolitan fringe areas of various types of cities and not limited to only a certain type of city;
- Continuity: the delineated metropolitan fringe area should be a relatively continuous physical space.

3.3.2. The Technical Route of the Delineation Method

With the above-mentioned four principles borne in mind, we construct the following morphology-based method to delineate the metropolitan fringe area of Shanghai. The technical route of the delineation method is described as follows (Figure 3).

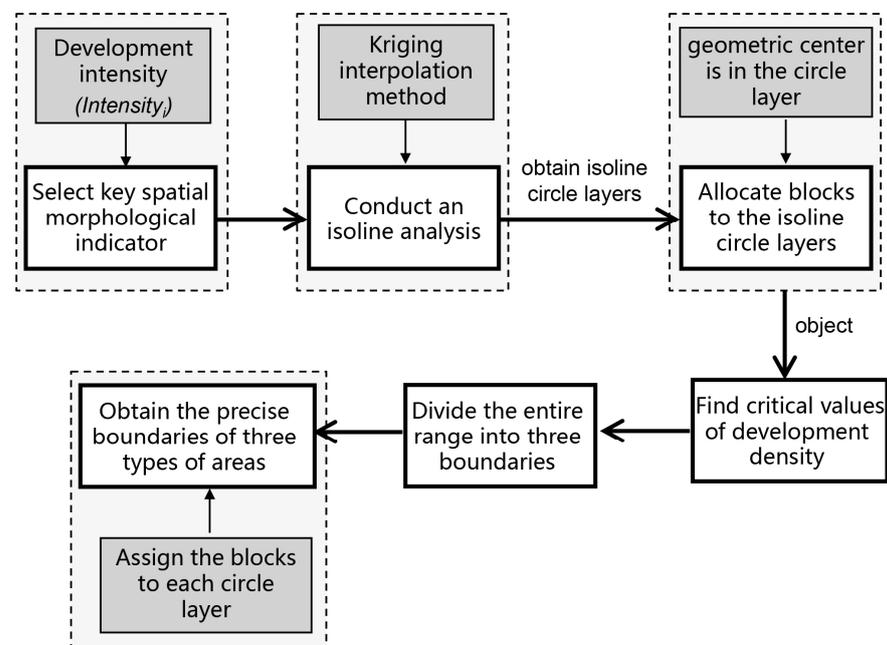


Figure 3. The technical route of the delineation method.

First, we select development intensity ($Intensity_i$) out of the three indicators as the key spatial morphological indicator to delineate the metropolitan fringe area. Compared with the other two indicators of building height ($Height_i$) and construction density ($Density_i$), development intensity is more comprehensive in terms of the spatial morphological information it contains. Note, however, that the other two indicators, together with development intensity, will be used to describe the characteristics of the spatial morphology of the metropolitan fringe area of Shanghai. In fact, development intensity, which is also known as plot ratio, is essential in achieving a sustainable built environment of an area and in maintaining the balance between providing enough living and working space and preserving open space for public use. Development intensity is also a key indicator for defining how much building volume can be constructed on a particular piece of land. Therefore, it affects an area's population and contributes to a city's overall urban planning and land development. It is generally believed that development intensity is much higher in the urban core of a city than in its metropolitan fringe area, which makes it possible

to delineate the metropolitan fringe area by analyzing the spatial distribution pattern of development intensity.

Second, we adopt the Kriging interpolation method to conduct an isoline analysis of block-level development intensity. A similar approach to drawing isolines of POI distribution density has also been used in the study of Dong et al. to delineate the metropolitan fringe area of Beijing [16]. By connecting the geometric centers of blocks with equal or similar development intensities, we were able to draw isolines of uniform development intensity and obtain a continuous distribution of different levels of block development intensities in the city. Specifically, the expression of the Kriging interpolation method is given as follows:

$$\hat{z}(X_0) = \sum_{i=1}^N \lambda_i z(X_i) \quad (4)$$

where $\hat{z}(X_0)$ represents the value of the predicted point at location X_0 , X_i represents the value of the sampled point i , and λ_i is the unique weight of point i . The weights are determined from the variogram based on the spatial structure of the data and are applied to the sampled points. One assumption for the Kriging interpolation method is that the values change uniformly in all directions, which is in line with the theoretical assumption that a city develops relatively uniformly in all directions to form an expansion structure from core to periphery.

Third, after obtaining the isoline circle layers of development intensity, we allocate all the blocks to the isoline circle layers based on the criterion of spatial join. Specifically, a block was assigned to a certain circle layer if the entire block or its geometric center was in the circle layer. Once the spatial block range of each circle layer was determined, we calculated the total construction area and the total block area of each circle layer, respectively. Similarly, following expression (3) for calculating the average development density at the block level, we can obtain the average development intensity value of each circle layer within the study area. The objective of calculating the average development intensity of each circle layer is to find the critical values of development density that separate the urban fringe area, the urban core area, and the rural area.

The fourth step is to find the above-mentioned critical values of development density. Here, the theoretical foundation is the circular layer development pattern of a city, which usually results in the formation of a near-circular concentric layout of the city. Under the influence of this expansion process, the intensity of urban development will gradually decline from the inner ring to the outer ring due to the declining attractiveness of a city's urban core area. Based on the definition and general characteristics of the metropolitan fringe area, we can expect that its internal fringe should experience a sudden change in development intensity from the urban core, while its external fringe should be an area from which development intensity declines gradually to the rural area. Specifically, the selection of the critical values relates to the specific value of development density of each circle layer, as well as the change rate of development density between adjacent circle layers. In brief, the critical values should be within the range of development density for two adjacent layers and the change rate should show a substantial decrease. Within the literature, there are usually two approaches to selecting the critical values. One is to establish a distance-intensity trend map, which aims to define the breakpoints between the urban core area, the metropolitan fringe area, and the rural area by reflecting the general trend of development intensity changes with the distance from the city center [13,22]. The second approach is to describe the development intensity change rate between two adjacent circle layers. The change rate is used to find the inflection point between the urban core area and the metropolitan fringe area, and between the metropolitan fringe area and the rural area [44–46]. Since the circle layers obtained in this study are not regular in shape, it is difficult to calculate the distance from each circle layer to the city center. Therefore, we adopt the second approach to identifying the critical values of development density that separates the urban core area, the metropolitan fringe area, and the rural area.

Finally, the circle layers with inflection points of development density were spatially joined, which divided the entire range of the study area into three boundaries. The circle layers within the inner boundary roughly correspond to the urban core area of Shanghai, the circle layers between the inner and the middle boundary roughly correspond to the metropolitan area of Shanghai, and those between the middle and the outer boundary roughly correspond to the rural area of Shanghai. To obtain the precise boundaries of the three types of areas, we then assign the blocks to each circle layer under the criterion that the geometric center of a block should fall within the range of a circle layer. In doing so, we could obtain the range of the metropolitan fringe area at the block level. However, this result is purely calculated through statistical analysis which does not consider the spatial reality of the metropolitan fringe area that it should be spatially continuous. Therefore, we further remove the disconnected parts and fulfill void areas to form a spatially continuous metropolitan fringe area.

4. Results

4.1. The Delineation Process and Result of Shanghai's Metropolitan Fringe Area

Following the above-described technical route, we first conduct the Kriging interpolation analysis of development intensity at the block level. Based on the classification method of natural breaks (Jenks), we divide the values of development intensity into 13 levels and plot the 13 lines of uniform development intensity (Figure 4). Note that the darker colors indicate higher development intensity values while the lighter colors represent lower development intensity values. Clearly, we can see that the development intensity distribution of Shanghai generally shows a decreasing trend from the center area to the periphery. However, the circle-layer distribution of development intensity does not strictly follow a regular concentric pattern but instead resembles a leap-frog type of distribution on the basis of a general circle-layer pattern.

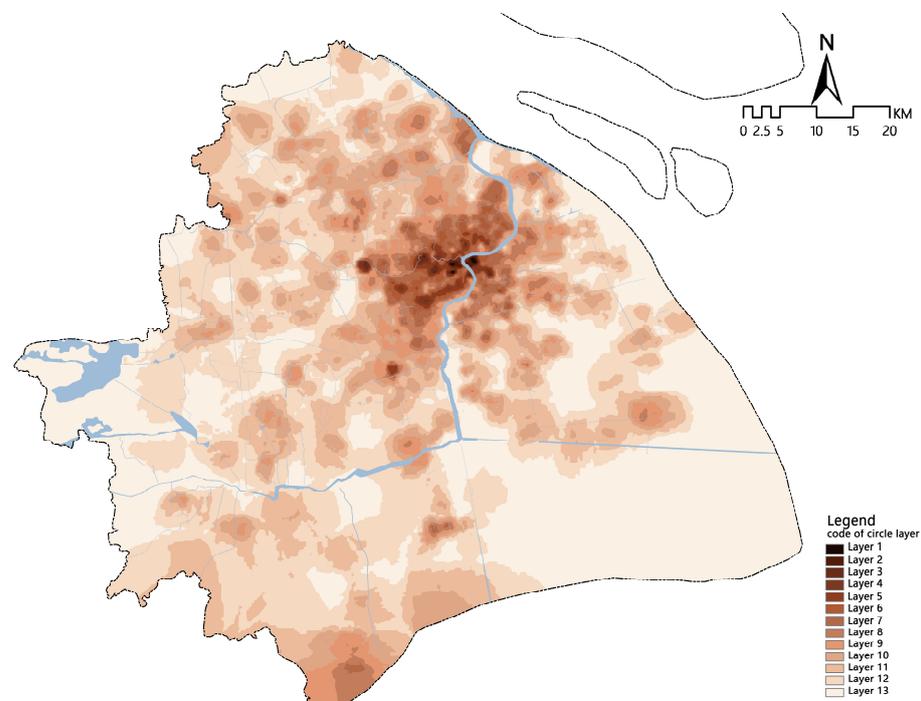


Figure 4. The isolines of uniform development intensity values within the study area.

We then allocate the blocks to the 13 isoline circle layers based on the criterion that the geometric center of a block should fall within the range of a certain circle layer. After that, we are able to calculate the average development intensity value of each circle layer. The result is shown in Table 1. Overall, we can see that the average development intensity

generally decreases from 7.72 in the inner circle layer to 0.02 in the outer circle layer. Clearly, this distribution pattern is in line with those of other indicators such as population density, nighttime lights, etc., which reflects the core-to-periphery expansion pattern of Shanghai's spatial morphology.

Table 1. The average development intensity of each circle layer.

Code of Circle Layer	Total Construction Area ¹	Total Floor Area	Average Development Intensity
1	105.95	13.73	7.72
2	156.97	35.57	4.41
3	6827.42	2499.66	2.73
4	12,811.25	8682.73	1.48
5	814.25	803.10	1.01
6	241.32	263.09	0.92
7	294.09	398.99	0.74
8	240.45	470.75	0.51
9	294.05	651.57	0.45
10	321.78	948.56	0.34
11	534.19	2768.07	0.19
12	671.99	8098.70	0.08
13	75.40	4697.01	0.02

¹ The construction area and the floor area are in hectares.

We further calculate the decrease rate of development intensity between two adjacent circle layers from the inner to the outer circle layer (Figure 5). Obviously, we can see that the decrease rate of the average development intensity has generally shown a declining trend from the first (0.75) to the fifth (0.12) circle layer, suggesting that the development intensity difference between two adjacent circle layers has been narrowing within the five circle layers. In contrast, the decrease rate of the average development intensity between the fifth and the eighth circle layer has experienced a remarkable decline, which is much higher than what has been observed between the five inner circle layers. Specifically, the decrease rate is 0.31 between the fifth and the sixth circle layer, 0.20 between the sixth and the seventh circle layer, and 0.09 between the seventh and the eighth circle layer. From the eighth to the thirteenth circle layer, the average development intensity has declined at a much higher rate than what has been observed between the fifth and the eighth circle layer. This suggests that areas between the eighth to the thirteenth circle layer might have mostly rural morphological characteristics.

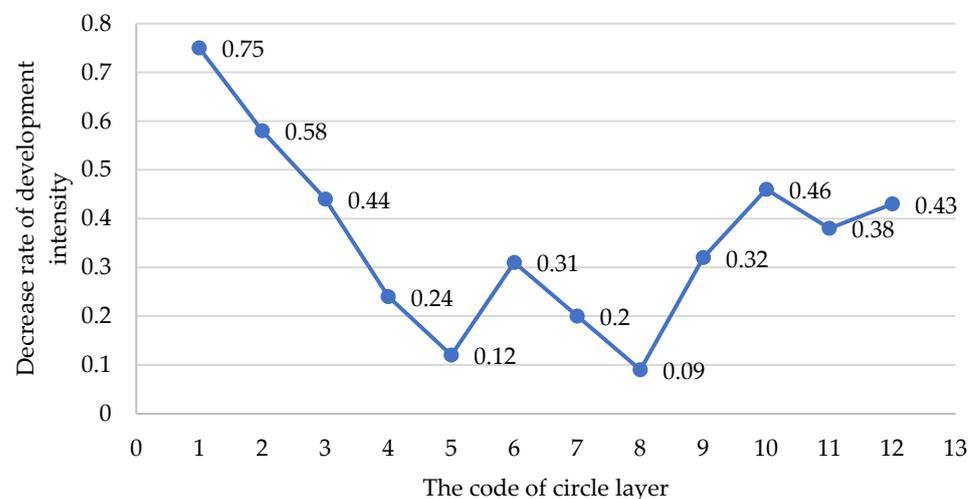


Figure 5. The decrease rate of development intensity from the first to the thirteenth circle layer.

Based on the above comparison of the decrease rate of development intensity, it is clear that the fifth and the eighth circle layers constitute the inflection points that can be used to initially delineate the boundaries of the urban core area, the metropolitan fringe area, and the rural area. Specifically, the fifth circle layer roughly separates the urban core area and the metropolitan fringe area, while the eighth circle layer roughly separates the metropolitan fringe area and the rural area. As shown in Figure 6, the urban core area is mainly located within the outer ring of Shanghai, as well as some scattered patches outside the outer ring. The metropolitan fringe area exhibits a finger-like extension pattern. It is worth noting that the inner boundary of the metropolitan fringe area and the outer ring of the city are spatially intertwined, while the outer boundary contains some partially disconnected patches. The rural area is scattered in the city's outer boundary as large discontinuous patches. This initial boundary identification lays the foundation for the delineation of Shanghai's metropolitan fringe area.

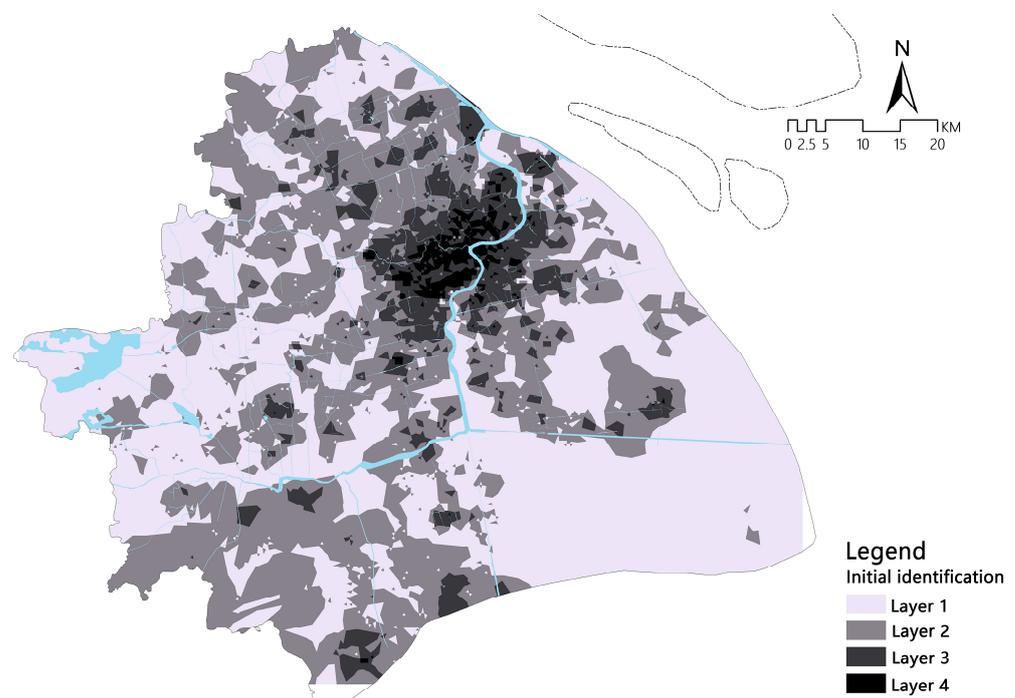


Figure 6. The initial boundary identification based on the decrease rate of development intensity.

After allocating the blocks to each circle layer, removing the discontinuous patches, and fulfilling the void areas surrounded by other blocks, we finally obtain the precise boundary of Shanghai's metropolitan fringe area (Figure 7). It is worth noting that while the area within the outer ring is traditionally considered as the urban core area of Shanghai, we find that the internal boundary of its metropolitan fringe area intertwines to some extent with the outer ring. Specifically, the metropolitan fringe area of Shanghai delineated in this study mainly include Yangxing Town and Luodian Town of Baoshan District; Jiading Town, Malu Town, Nanxiang Town and Huangdu Town of Jiading District; Huacao Town, Tangwan Town, and Pujiang Town of Minhang District; Jitong Town and Xinqiao Town of Songjiang District; and Zhoupu Town, Hangtou Town, Caou Town, Gonglu Town, Tang Town, and Chuansha Town of Pudong New District.

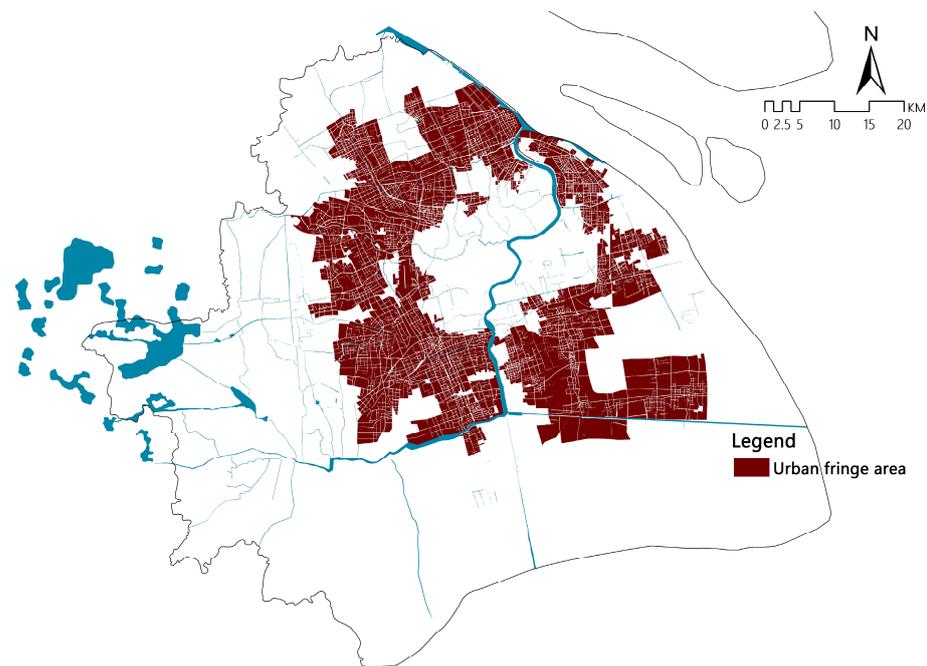


Figure 7. The delineation of Shanghai's metropolitan fringe area.

4.2. Spatial Morphological Characteristics of Shanghai's Metropolitan Fringe Area

4.2.1. The Distribution Patterns of Building Height

The metropolitan fringe area of Shanghai has a total number of 190,714 buildings, which can be classified into five types based on their height and storeys, including low-rise buildings (residential buildings with less than three storeys and public buildings below 9 m), lower-middle-rise buildings (residential buildings with four to six storeys and public buildings below 18 m), mid-rise buildings (residential buildings with seven to nine storeys and public buildings below 24 m), high-rise buildings (residential buildings with ten to thirty-two storeys and public buildings below 100 m), and super high-rise buildings (residential buildings with more than thirty-three storeys and public buildings above 100 m).

Overall, the metropolitan fringe area of Shanghai has been largely dominated by low-rise and lower-middle-rise buildings. As shown in Table 2, the number of low-rise buildings is 115,815, which accounts for 60.90% of the total. The number of lower-middle-rise buildings is the second largest, with a proportion of 30.79% of the total. In contrast, the total share of mid-rise buildings, high-rise buildings, and super high-rise buildings is less than 10%. Specifically, the shares of the number of mid-rise buildings and high-rise buildings are both less than 4.5%, while the number of super high-rise buildings is the lowest, which only accounts for 0.01% of the total.

Table 2. The number of buildings with different levels of height.

Types of Buildings	Number	Share
Low-rise building	115,815	60.90%
Lower-middle-rise building	58,562	30.79%
Mid-rise building	8395	4.41%
High-rise building	7388	3.88%
Super high-rise building	14	0.01%

Figure 8 shows the spatial distribution patterns of different types of buildings, with deeper colors indicating higher levels of agglomeration and lighter colors reflecting lower levels of agglomeration (i.e., more scattered). As for low-rise buildings, their distribution

on the two sides of the Huangpu River is inconsistent. Specifically, low-rise buildings have mainly agglomerated in the Puxi area (i.e., to the west of Huangpu River), especially on its southern side, while the distribution of low-rise buildings has been generally scattered in the Pudong area (i.e., to the east of Huangpu River). From the perspective of land use functions, there are a large number of industrial plant buildings on the southern side of the Puxi area. Most of these industrial plants are in labor-intensive industries, so their construction types are mainly characterized by low-rise buildings.

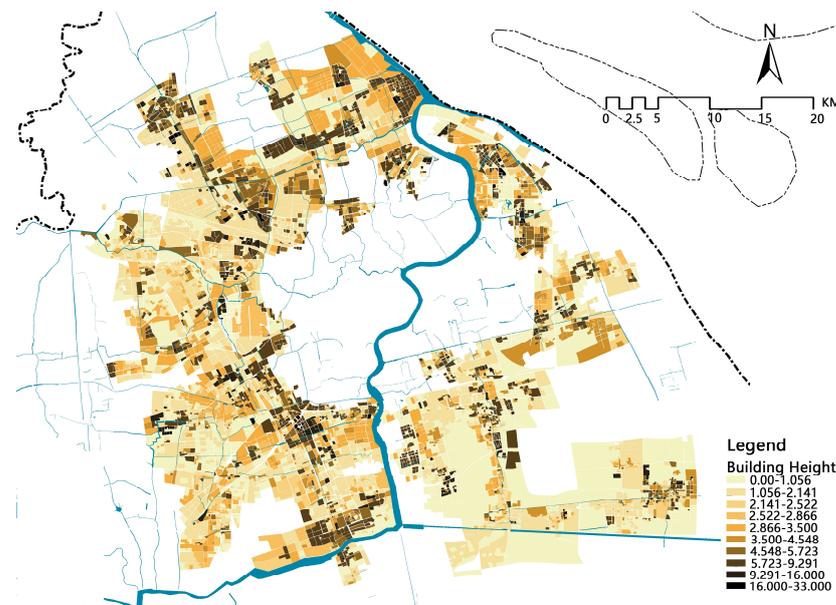


Figure 8. The spatial distribution of buildings with different height levels.

As for lower-middle-rise buildings, their spatial distribution has been more dispersed than low-rise buildings. They have mainly agglomerated in two areas alongside the outer ring of Shanghai, which are the Hujia Expressway–Baoan Highway axis belt and Minsong road. Further, there are six smaller clusters of lower-middle-rise buildings, including the Baoan area, the Baoxin real estate building area, the northern Jiading area, the Huajing area, Gangcheng road, and Huinan Town. Influenced by relevant planning policies, the Baoan area and Gangcheng road in the north have mainly focused on industrial land and residential land development. Because the two areas were developed relatively earlier, they have mainly focused on the construction of lower-middle-rise buildings. Huajing District and Huinan Town in the south are close to the urban center, with relatively complete public service facilities and a large number of residential buildings.

The spatial distribution of mid-rise buildings is relatively concentrated, with the Huxiang–Yunchuan Expressway area, the Yanggao north road area, and the Shanghai–Hangzhou Expressway area being three main clusters. In contrast, the spatial distribution of high-rise buildings is more dispersed and generally scattered as a whole. Due to the small number of super high-rise buildings, which mainly include residential, mixed commercial, and commercial hotel buildings, they are generally scattered in the northern part of the metropolitan fringe area.

Overall, the spatial distribution of buildings in the metropolitan fringe area has been characterized by a relatively homogeneous distribution of low-rise and lower-middle-rise buildings, a circular agglomeration of mid- and high-rise buildings in the inner edge and cluster distribution in the outer edge, and a relatively scattered distribution of super high-rise buildings. These characteristics are generally in line with the common expansion trend of building height from core to periphery.

4.2.2. The Distribution Patterns of Building Density

The building density of blocks in the metropolitan fringe area ranges from 0.876 to 0.036. However, the building density of nearly 70% of the blocks is less than 0.25, suggesting that the metropolitan fringe area is mainly characterized by low-density development. Furthermore, the spatial distribution of building density in the metropolitan fringe area has been mainly characterized by a multi-section layout. Influenced by traffic and natural water conditions, farmland green space and other barriers, the metropolitan fringe area is roughly divided into six main areas. At the same time, each area's own land use type and construction timing are different, resulting in different internal structures. However, these areas have been generally distributed alongside one or several traffic corridors. Specifically, we can see that several clusters with relatively higher values of building density have formed in the metropolitan fringe area, and the distribution of these clusters has generally shown three different patterns (Figure 9).

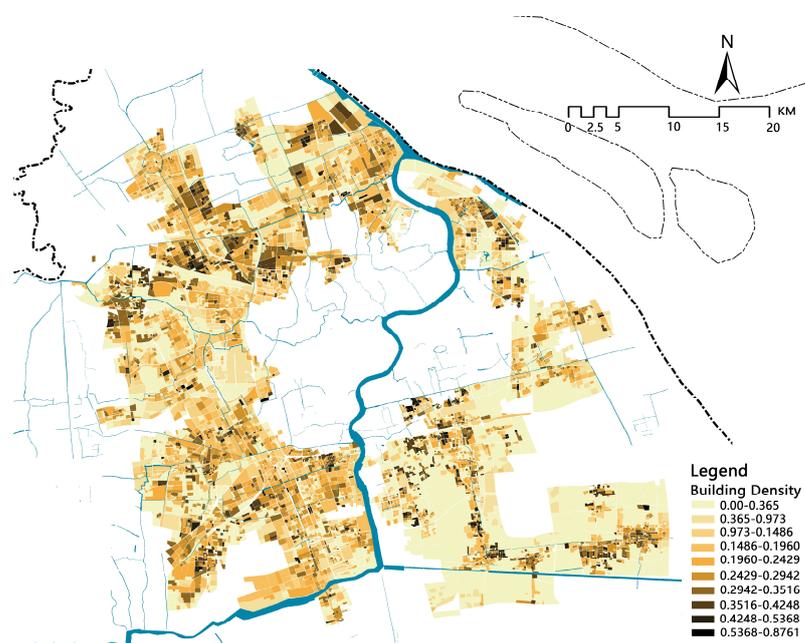


Figure 9. The spatial distribution of building density.

The first distribution pattern refers to the linear layout of building density clusters along both sides of the main corridor lines. One of the most typical examples of this pattern is the distribution of the three clusters in Xinzhuang Town, Xinqiao Town, and Huayang Town, which is mainly alongside the Beijing–Hangzhou high-speed railway corridor and separated by areas with relatively lower values of building density. Moreover, the three clusters differ a lot in terms of their land use functions. Specifically, Xinzhuang Town is dominated by residential and public welfare land, Xinqiao Town is characterized by a mix of residential and agricultural and forestry land, and Huayang Town is dominated by industrial land.

The second distribution pattern refers to the layout of one or several areas with relatively lower values of building density surrounded by areas with relatively higher values of building density. The Shanghai Hongqiao Airport and its surrounding area are typical representatives of this distribution pattern. Due to the functional requirements, the building density of Hongqiao Airport Station is relatively low, while its surrounding areas are dominated by a high-density development of residential and industrial land. Such a spatial layout forms an encircling pattern of low-building-density areas surrounded by high-building-density areas.

The third distribution pattern refers to the layout of a larger cluster containing several scattered smaller clusters. This distribution pattern can be clearly found in the Jiading–

Baoshan area, where there are many smaller areas with relatively higher values of building density, such as the northern area of Jiading District, Yuepu Town, Luodian Town, and Liuxing Town.

4.2.3. The Distribution Patterns of Development Intensity

The development intensity of blocks in the metropolitan fringe area ranges from 0.01 to 9.62, with 77.24% of the blocks having a development intensity value lower than 1. The average value of development intensity for the total area is 0.44, suggesting that the metropolitan fringe area has been mainly characterized by a relatively lower level of development intensity.

The spatial distribution of development intensity is shown in Figure 10. Two major characteristics of the distribution pattern can be discussed here. On the one hand, the values of development intensity have been generally decreasing from the inner edge of the metropolitan fringe area to its outer edge. The outer ring of Shanghai, which intertwines with the inner edge of the metropolitan fringe area, has played an important role in organizing the clusters with higher values of development intensity. Alongside the outer ring are clusters with a relatively higher level of development intensity, such as Baoshan Town, Yangxing Town, Luodian Town, and the northern part of Jiading District. These areas are dominated by residential land which is also mixed with industrial and commercial land.

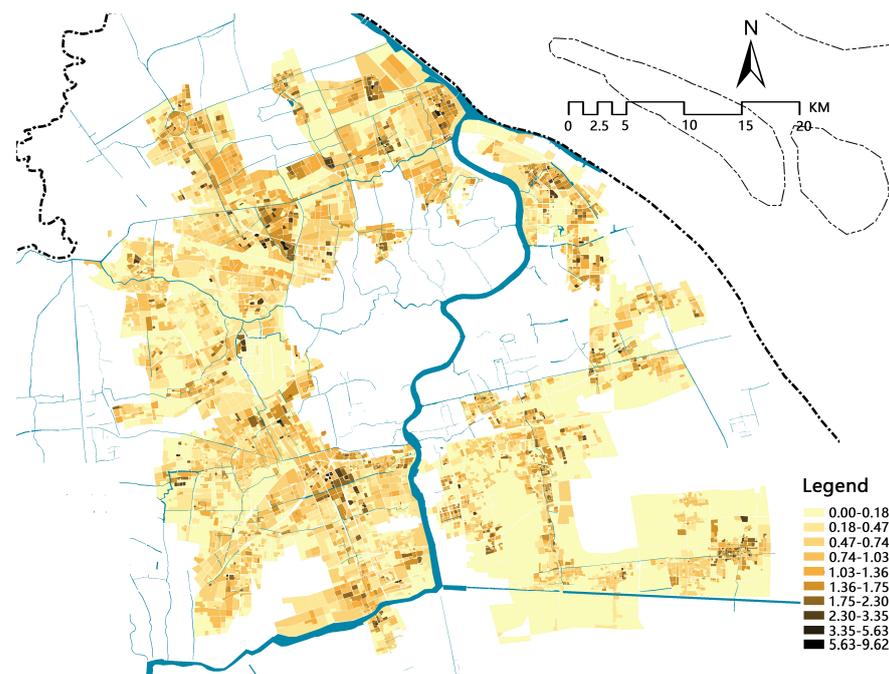


Figure 10. The spatial distribution of development intensity.

On the other hand, development intensity has been gradually declining from areas surrounding the outer ring to the outer edge of the metropolitan fringe area through a number of urban development corridors, where clusters with relatively higher values of development intensity agglomerate due to good conditions such as traffic location. Typical examples of these development corridors include the Shanghai–Jiading Expressway and the Shanghai–Hangzhou Highway, both sides of which are scattered with clusters with a relatively higher level of development intensity. Due to the differences in development modes and expansion elements, development intensity in the outer edge of the metropolitan fringe area is mainly distributed along different types of development corridors. For instance, some buildings such as factories and warehouses, which usually require higher levels of accessibility, have been often constructed along the main road lines and river systems. Their

outward extension usually leads to the formation of an industrial corridor. Similarly, due to the construction of line-type infrastructure such as subways and highways, the local government of Shanghai has distributed some residential land along these infrastructures, thus contributing to the formation of a residential corridor.

5. Discussion

5.1. Validation of the Delineation Result

In this study, we propose a morphology-based method to delineate the metropolitan fringe area of Shanghai. The delineation result can be validated from the following aspects. First, in terms of the geographical locations of the metropolitan fringe area, we can see that it is mainly located between the outer ring and the suburban ring area of Shanghai, accounting for 24.65% of the total area of Shanghai. By referring to the Master Plan of Shanghai, we find that the metropolitan fringe area is defined as an area comprising 26 towns along the outer ring road. Therefore, the range of the metropolitan fringe area of Shanghai identified in this study generally corresponds to what has been defined in its Master Plan.

Second, judging from the shape of the metropolitan fringe area, we think it also reflects the impact of rapid urbanization as well as the general attributes of the metropolitan fringe area. Specifically, the metropolitan fringe area identified in this study has shown a ring-radiating trend, which is basically distributed in a ring around the spatial boundary of the urban core. However, the internal and external boundaries of the metropolitan fringe area are not in regular shape. For instance, in terms of its external boundary, there are some convex areas where some new towns are located. These areas are generally far away from the city center and are connected and spread through the main traffic trunk road. In addition, there are some depressed areas that are mainly influenced by the infiltration of farmland or other non-urban construction land.

Third, the metropolitan fringe area identified in this study has a typical type of land use function. As shown in Table 3, the proportion of urban construction land and non-urban construction land is 61.46% and 38.54%, respectively, among which residential land accounts for 23.58%, industrial land accounts for 26.8%, and agricultural and forestry land accounts for 30.33%. By contrast, the proportion of mixed land use is the lowest, which is only 0.18%. Additionally, the proportion of commercial service facilities is 2.30%, which is much lower than that of the urban core area. Taken together, this suggests that the urban construction land has been dominated by residential and industrial functions, while the non-urban construction land has been dominated by agricultural and forestry functions.

Table 3. The area and share of different types of land in the metropolitan fringe area.

Types of Land	Types of Functions	Area (Hectares)	Share
Urban construction land	Residential	29,606.3	23.58%
	Industrial	33,655.6	26.80%
	Commercial	2893.2	2.30%
	Public service	2053.5	1.64%
	Mixed use	224.3	0.18%
	Others	8747.4	6.96%
Non-urban construction land	Agricultural and forestry	38,082.9	30.33%
	Others	10,314.7	8.21%

5.2. The prototype of the Spatial Structure of the Metropolitan Fringe Area

The spatial characteristics of Shanghai's metropolitan fringe area reflect that it is a relatively independent and complete spatial form that can be divided into five basic morphological elements, including residential and industrial clusters, shadow spaces accompanying clusters, corridor lines, green wedges, and surfaces. These five spatial elements have constituted the specific morphological characteristics that distinguish the

metropolitan fringe area from the urban core area and the rural area. The definitions and significance of the five spatial elements are described as follows.

Residential and industrial clusters and their accompanying shadow spaces represent the areas in which the spatial form has an obvious elevated or depressed change compared with the surrounding areas. Specifically, residential and industrial clusters often include residential areas and industrial parks, which have a relatively higher level of development intensity. In contrast, the shadow spaces accompanying these clusters usually have a relatively lower level of development intensity. The existence of clusters in metropolitan fringe areas can also be linked with the polycentricity of urban spatial structures, which has become increasingly common in China and European countries and has been widely investigated in the literature [47–50].

Corridor lines and green wedges refer to the main leading factors that strengthen or weaken the development of a certain area. Corridor lines are important for connecting the urban core, the metropolitan fringe, and the rural areas. Furthermore, they are key elements of directional expansion from core to peripheral areas. These areas typically feature good transportation conditions, which facilitate the formation of scattered and discontinuous clusters. Green wedges are linear elements that represent the gradual inward penetration of the external natural environment. Different types of green wedges have different penetration distances, thus resulting in long and short wedges in the metropolitan fringe area.

Surface elements refer to relatively flat areas, the main function of which is to support the development of point elements and line elements. They help form the bases and backgrounds for the development of the metropolitan fringe area. These areas carry the basic functions and have the characteristics of stable development, a single function, and a low degree of compounding.

The interaction of the five spatial elements constitutes the prototype of the spatial structure of the metropolitan fringe area of Shanghai (Figure 11), which is also of great significance and value to other cities' fringe areas. Overall, the metropolitan fringe area is not only the fringe of the urban core area but also the fringe of the rural area, indicating strong interactions between these areas. Therefore, the prototype of this spatial structure can be interpreted from three aspects. First, the inner interaction zone is not only the dominant area of spatial position but also the dominant area of urban functions, with high traffic accessibility and complete public service facilities. The overall distribution of this zone shows an agglomeration pattern of contiguous clustering. The middle interaction zone generally shows a linear agglomeration pattern, consisting of residential and industrial clusters of high development intensity interlaced with shadow spaces or green wedges of low development intensity. The outer interaction zone is mainly scattered with clusters formed by new towns.

5.3. Implications for Urban Planning and Design

It is clear that the metropolitan fringe area has become a strategic area for a city's future growth; thus, obtaining a better understanding of the development of the metropolitan fringe area is of great significance to a city's high-quality development [37]. This study shows that the metropolitan fringe area can not only be understood from the traditional perspectives of land use or population density but also can be interpreted from a spatial morphology perspective, which we believe could contribute to the planning and design of the metropolitan fringe area. Specifically, though the metropolitan fringe area has been traditionally characterized by discontinuous, low-density, and low-intensity development, the empirical results of this study suggest that there is significant heterogeneity within the metropolitan fringe area in terms of the distribution of spatial morphological characteristics.

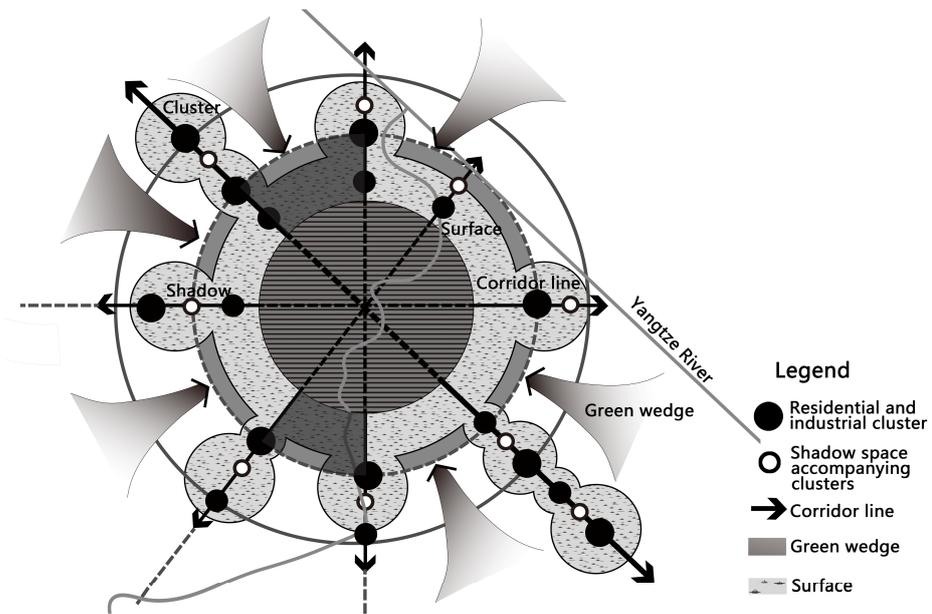


Figure 11. The prototype of the spatial structure of the metropolitan fringe area.

The prototype of the spatial structure of the metropolitan fringe area that we propose in this study highlights the importance of considering such heterogeneity in the planning and design of the metropolitan fringe area. Residential and industrial clusters, shadow spaces accompanying clusters, corridor lines, green wedges, and surfaces are five key spatial elements that distinguish the metropolitan fringe area from the urban core area and the rural area. They are also key elements that determine the spatial morphology of the metropolitan fringe area. In the case of Shanghai, some of the residential and industrial clusters identified in this study roughly correspond to the geographical locations of the new towns that have been planned and constructed by the Shanghai municipal government. Moreover, these new towns are well connected with the urban core areas through various corridor lines. This raises some interesting topics that are worth further investigation. For instance, how have the new town plans of Shanghai influenced the morphological characteristics of its metropolitan fringe area, especially in terms of the five key elements? Why have some residential and industrial clusters not been identified as potential new towns? An investigation of these questions would provide a better understanding of the planning and design of the metropolitan fringe area, not only for Shanghai but also for other cities in general [45].

6. Conclusions

6.1. Working Summary and Main Conclusions

First, the delineation method of the Shanghai metropolitan fringe area was proposed with four principles: objectivity, simplicity, universality and continuity. Then, based on its definition from the perspective of spatial morphology, three indicators were selected, and we used the Kriging interpolation method to explore the preliminary spatial boundary of the metropolitan fringe area. The result was validated afterward, and we continued to discuss the prototype of its spatial structure, which was divided into five elements: residential and industrial clusters, shadow spaces accompanying clusters, corridor lines, green wedges, and surfaces. Finally, spatial heterogeneity was proposed for the planning and design of the metropolitan fringe area.

To sum up, in this paper, we develop a morphology-based method to delineate and characterize the metropolitan fringe area of Shanghai by drawing upon a spatial morphology dataset. Overall, the metropolitan fringe area identified in this study accounts for 24.65% of Shanghai's total area and is mainly composed of residential, industrial,

and agricultural and forestry land. The shape of the metropolitan fringe area is basically circular, with its inner edge intertwining with the outer ring of Shanghai. Though the distributions of spatial characteristics represented by building height, building density, and development intensity differ from each other, they all suggest that the metropolitan fringe area of Shanghai bears spatial characteristics that are distinctive compared with the urban core area and the rural area. Furthermore, the metropolitan fringe area of Shanghai contains five key spatial elements, which are residential and industrial clusters, shadow spaces accompanying clusters, corridor lines, green wedges, and surfaces. The interaction of the five spatial elements lays the foundation for the prototype of spatial structure of the metropolitan fringe area of Shanghai.

6.2. Planning Suggestions

While the metropolitan fringe area has been traditionally considered as distinctive compared with the urban core and the rural area, this paper empirically shows how the metropolitan fringe area is distinctive in terms of spatial morphological characteristics such as building height, building density, and development intensity, which is also of great significance to promoting the planning and design of the metropolitan fringe area. As the metropolitan fringe area plays a really important role in connecting the urban core and the rural area, an improvement in connectivity of the road traffic system is essential. Also, to promote the vitality, increasing fundamental public service facilities such as hospitals and schools is an effective approach.

6.3. Prospects for Follow-up Research

However, this study has some limitations that could serve as departure points for future research. So, further research on urban fringe areas can be carried out from the following perspectives:

- (1) Due to data constraints, we were unable to analyze how the metropolitan fringe area has evolved during China's rapid urbanization process, which varies from period to period with its constant change. So, if there is more comprehensive and consistent data, the spatial-temporal characteristics can be determined afterward.
- (2) In addition, the mechanisms behind the heterogeneity in the distribution of spatial morphological characteristics need to be further explored, such as by conducting a correlation analysis between population change and development intensity.
- (3) Shanghai is a representative mega-city with rich geographic resources—for example, the Yangtze River and the Suzhou River—so different parts of its metropolitan fringe area vary greatly. Thus, further research should be conducted on the detailed characteristics of various sub-regions, respectively, in order to put forward more specific suggestions for the planning and design of Shanghai's metropolitan fringe area. Moreover, subsequent studies can analyze the situation for small- and medium-sized cities as well.

Author Contributions: Conceptualization, W.X. and J.Y.; methodology, W.X.; data curation, W.X.; writing—original draft preparation, W.X.; writing—review and editing, W.X. and J.Y.; visualization, W.X.; funding acquisition, W.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China, grant number 52208063; Natural Science Foundation of Jiangsu Province, China, grant number BK20220424.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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