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Determining the Spatial Distribution Characteristics of Urban Regeneration Projects in China on the City Scale: The Case of Shenzhen

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Abstract: Urban regeneration (UR) has been a leading concern in urban studies globally. China's rapid urbanization has undergone profound urban decay and social contestation, for which UR has emerged as a viable solution. However, UR is not without its drawbacks. It has caused emerging spatial and planning problems; however, few studies have explored the characteristics and issues of UR from the view of spatial analytics on the city scale. This study aims to depict the distribution characteristics of UR projects in Chinese cities and to reveal whether it meets the requirements of urban development from the planning perspective. The nearest neighbor index and its hierarchical clustering, as well as kernel density estimation are used in conjunction to investigate the spatial distribution characteristics; and the relationship between project distribution and each urban development indicator is explored using mixed spatial characteristics analyses, such as buffer analysis, space syntax, and heat mapping. Considering Shenzhen as the empirical study city, this research is based on all officially released data of implemented UR projects between 2010 and 2021. The findings imply that the UR projects in Shenzhen are mostly located in areas with higher economic development levels and accessibility with areas witnessing industrial restructuring and severe urban decay being prone to be designated for UR initiatives. The spatial distribution characteristics disclose the challenges inherent in the mix of top-down and market-driven UR approaches as well as the dilemma of the center-periphery pattern in UR implementation. Furthermore, the contradiction between the growing population and limited land resources as well as the barriers to industrial clustering formation are also revealed. This study enriches the methodological framework for spatial and visualization studies of urban regeneration in worldwide cities and sheds light on how to promote UR in regard to urban sustainability with ramifications for future urban development in other Chinese cities.

Keywords: urban regeneration; spatial characteristics; distribution; China; Shenzhen

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1. Introduction

Globally, the soaring urban population [1] has significantly engendered the rigid demand for a high-quality urban environment. Under this situation, severe urban problems, such as inefficient use of urban land, limited land carrying capacity, and the degradation of old urban areas are increasingly being witnessed worldwide [2–4], China is no exemption [5]. Due to limited land resources in many Chinese cities, addressing urban problems through urban sprawl is becoming increasingly infeasible and unsustainable. In Shanghai, for instance, only about 5% of urban land is available for new building development; in Shenzhen, only trivial 5900 hectares of urban land are available for development [6]. In this context, urban regeneration (UR) has been in the vanguard of urban development strategy in most Chinese cities [7,8].

As a critical strategy for improving urban areas and combating urban decay, UR both enacts physical improvements and achieves multiple socioeconomic objectives [9–12]. It indicates the demolition and reconstruction of old buildings/neighborhoods, or rehabilitation through minor physical change, such as elevator installation, building structure reinforcement, and the provision of facilities and amenities. In China, there exist around 160 thousand old neighborhoods, covering 800 million m^2 of built-up land and involving over 42 million families [13]. Up to now, more than RMB 10 trillion have been invested in UR projects [14]. However, in terms of overall prospective projects, this scale is only the tip of the iceberg.

To further promote UR, the Chinese government has promulgated a plethora of policies and developed urban development initiatives regarding UR. To mention a few, at the Central Work Conference (CWC) of Urbanization in 2015, promoting urban restoration and accelerating the rehabilitation of the old neighborhoods are proposed as key future urban development directions in China [15]. In 2019, the CWC of Economy also emphasized the need of enhancing the quality of old residential buildings through UR [16].

In 2020, the "14th Five-Year Plan for National Economic and Social Development and the 2035 Visionary Goals" explicitly proposed "the implementation of actions for UR", marking that UR has been incorporated into national medium- and long-term development plan as a core strategy [17]. In other words, to fulfil the growing rigid demand, improve citizen well-being, and promote urban prosperity, considerable new UR projects need to be planned and implemented in the near future [12].

UR is rooted in the urban system and features multi-disciplinary, multi-dimensional, and complex characteristics [18]. Globally, UR has had unforeseen negative repercussions in practice as a major approach to increasing the value of land use and improving the living environment [1,19]. With the implementation of UR, a series of spatial and planning concerns are frequently occurring, such as the conflict with other planning [20], spatial injustice [21,22], gentrification [23–25], and traffic congestion [26]. The aforementioned issues may generate further impediments for future UR projects in the same area, including increases in UR costs, difficulties in obtaining public agreements, and challenges to the environmental carrying capacity [27–30].

The above problems are significantly prominent in the Chinese context [11,31]. It is widely known that blindly performing UR projects without proper planning is the major cause of the above problems in China [4,32]. To effectively address the issues, the first priority should be to comprehensively and spatially evaluate the implementation of UR projects. This helps to depict the existing issues from a planning standpoint. Accordingly, it can offer lessons on future UR planning and strategies, therefore, fulfilling the objective of sustainable UR [19,33].

However, few studies have deployed spatial analysis to investigate the characteristics and issues of UR projects on the city scale, let alone in the Chinese context. Therefore, this study aims to explore the distribution of UR projects in a representative Chinese city and determine if it fits the needs of urban development from a planning perspective. The following research questions are answered: What are the spatial and temporal distribution characteristics of UR? Then, what are the relationships between UR distribution and different aspects of urban development (public facilities, population, house price, urbanization function, and urbanization form)?

Finally, whether the implementation of UR meets the needs of urban development from the planning perspective? The nearest neighbor index (NNI), nearest neighbor hierarchical clustering (NNHC), and kernel density estimation are jointly used for exploring the spatial distribution characteristics. The mixed spatial characteristics analyses, including buffer analysis, space syntax, and heat mapping, are used to solve the second question. Drawing on the above, the problems regarding urban development brought about by urban regeneration are discussed, which address the third question. As a pioneer city of UR in China, Shenzhen was selected as a case study area.

Accordingly, this paper is structured as follows: Section 2 presents the literature review regarding the UR in China, the UR spatial analysis, and the research methods for analyzing spatial characteristics; Section 3 introduces the research methodology and data sources; Section 4 analyses the characteristics of UR projects spatial distribution by adopting mixed-methods; Section 5 is the discussion section; and finally, our conclusions are provided in Section 6.

2. Literature Review

2.1. UR in China

In different eras, the historical development of UR in China is interwoven with its economic level, political environment, and cultural setting [34,35]. Chinese UR has gone through various stages of development as it transitioned from a planned economy to a market one [36]. Prior to 1990, China's urbanization rate was modest, resulting in the delayed growth of UR projects [37]. The projects were mostly small-scale and focused on improving building safety as well as basic living amenities [35].

During the 1990s and 2000s, China experienced a soaring urbanization period. At this stage, UR was significantly influenced by the skyrocketing real estate market. Developers aim to secure high-value urban land for real estate development, and government sectors had a strong motivation to collect fiscal revenue through land leasing. Numerous UR projects implemented in this context were characterized with large-scale demolition and reconstruction [38–40].

With the scarcity of available urban land and the reconsideration of conventional urban development modes since the 2010s, the connotation of UR has steadily evolved. This highlights the notion of "people-oriented development", which prioritizes genuine improvements in inhabitants' well-being over urban economic growth. To achieve sustainable urban development, economic, social, and environmental interests must be integrated into the UR process [7,8,41].

However, the evolutions of connotation may not instantaneously manifest in UR planning optimization, as the current UR planning system has a strong path dependence stemming from the conventional top-down urban redevelopment institution [42]. Thereby, analyzing the status quo of UR distribution on the city scale is a critical step to understanding what problems are generated under the current planning system. The preceding background is based in China, yet the significance may be mirrored much more broadly in the context of global sustainable development.

2.2. Spatial Analysis of UR

There exist plenty of research about spatial analysis regarding UR from diverse aspects. The current application can be divided into two dimensions. The first dimension is decision-making and project evaluation [43–45]. Perez, et al. [46] developed a new spatial decision support system (SDSS) to explore sustainable UR at the community level. La Rosa, Privitera, Barbarossa, and La Greca [20] evaluated the spatial benefits of UR by establishing buffer zones and various indicators. The second dimension is urban spatial planning, such as the research on how underground space can contribute to UR [47], the depiction of public space regarding UR [26,48,49], and the analysis of UR spatial patterns by using spectra [50].

Until recently, limited efforts have been made in the field of research on the spatial characteristics of UR projects. By adopting exploratory spatial data and superimposed analysis, Lai, et al. [51] discovered that urban village redevelopment occurred mainly in city centers and suburbs, with a propensity to cluster. Tong, et al. [52] revealed the spatial characteristics of urban villages in Shenzhen based on a mathematical model of spatial analysis. However, these studies either explored the spatial characteristics of a specific type of UR project or employed a small sample size. Due to the drawbacks, these studies failed to provide a holistic picture of UR spatial characteristics on the city scale.

2.3. Research Methods for Analyzing Spatial Characteristics

Based on the existing research studies, there are abundant methods for spatial characteristic analysis, and these are shown in Table 1.

Table 1. Spatial characteristic analysis methods.

Methods	Function	Source
Moran's I	Analyzing the spatial autocorrelation of attribute values	[53,54]
Nearest Neighbor Index (NNI)	Measuring the degree of spatial data clustering	[55–57]
Nearest Neighbor Hierarchy Clustering (NNHC)	Analyzing the hot spots of elements by clustering spatial elements	[58,59]
Kernel density	Analyzing the agglomeration of elements by calculating the density of spatial elements in the surrounding areas	[60–62]
Ripley's K Function	Analyzing the degree of spatial aggregation or diffusion of centroid feature	[63]
Getis-Ord	Analyzing hot and cold spots in the particular space	[64]
Standard ellipse difference	Estimating distribution trends and central locations of spatial elements	[61,62,65]
Information entropy model	Assessing the degree of the mixing of spatial elements	[60,66,67]
Spatial interpolation	Estimating the data of unknown points from the data of known points	[68,69]
Space syntax	Dividing the space and analyzing its complex relationships	[70,71]

Different methods for analyzing spatial attributes can yield insights from various viewpoints. Moran's I and Getis-Ord are both more concerned with the correlation of feature attribute values. For instance, Guo, Yang, Xiao, Xia, Jin, and Li [54] determined the spatial correlation by employing the Moran index on the temperature data at the surface. Before using Moran's I, the targeted region must be clearly divided, thus, grouping the data accordingly [51].

NNI, NNHC, and Ripley's K function only analyze the agglomeration of spatial elements from the spatial position. Specifically, the difference between NNHC and Ripley's K function is that the former is preset as "cluster", while the latter is "distance". The latter cannot present the agglomeration of elements from the map. Kernel density estimation is the simplest but also the most imprecise approach. It can only depict the approximate location of the factor clusters and is frequently used in combination with other methods.

Given that UR is anchored in the urbanization process in the Chinese context, indicators for measuring urbanization development levels can be used to indicate the surrounding urban development level of UR projects.

In general, six indicators are utilized to depict the urbanization development level regarding urbanization public facilities, the urbanization population, the urbanization economy, urbanization functions, urbanization forms, and the urbanization ecology [72–74]. The indicator of urbanization ecology is most fitted for usage in low-density or underdeveloped urban areas. The urban metro system is frequently chosen as the measurement item for urbanization public facilities [75]. In many studies, it is the consensus that house prices can well represent the urbanization economic level [76,77]. The urbanization form is represented by road networks and density zones. As demonstrated by other studies, apart from the use of urban land, the configuration of the road networks can also strongly affect the urbanization form [78].

3. Materials and Methods

3.1. Research Framework

To conduct research more comprehensively, this paper deploys mixed methods of spatial characteristic analysis based on the literature review and characteristics of research objectives. First, this paper classifies UR projects based on the object, time, and scale. Secondly, it analyzes the agglomeration of UR projects in the case study area (research question 1) by combining the kernel density estimation, NNHC, and NNI. The spatial clustering characteristics of the factors are roughly estimated by kernel density estimation. NNHC can present the specific spatial clustering areas of UR projects. NNI calculates the degree of agglomeration of UR projects on the city scale.

Combining the three methods, this not only quantifies the project agglomeration but also shows the agglomerated area of different projects. Thirdly, the relationship between different urban development indicators and UR project distribution is probed (research question 2). Buffer analysis is adopted in particular to analyze the distribution of UR projects around the metro system. Kriging interpolation is utilized to estimate the distribution of house prices.

The mix of urban functions is analyzed by establishing an information entropy model. The road network is explored through spatial syntax. The distribution of the population is presented by a heat map. Finally, policy implications are proposed, and it is revealed if the UR implementation fits the needs of urban development by incorporating the quantitative and visualized findings, the current urban planning, earlier research works, and the planning theories (research question 3). Figure 1 describes the basic research process.

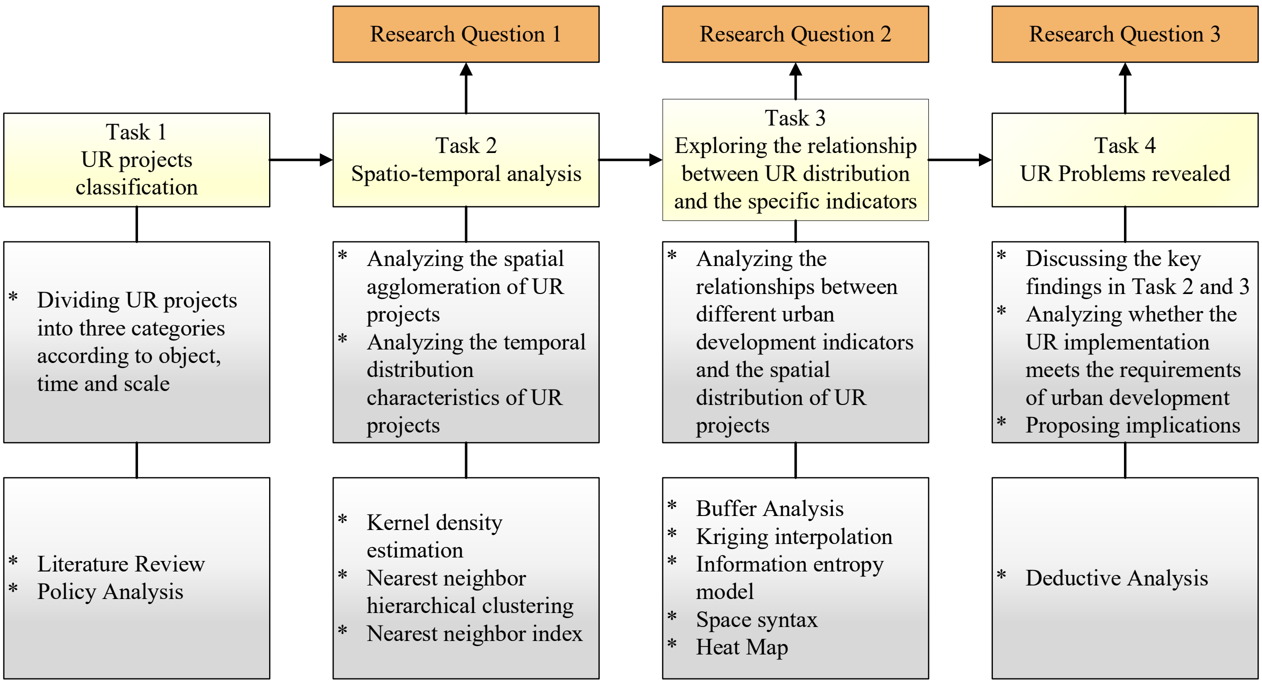


Figure 1. Research process.

3.2. Research Methods

3.2.1. Nearest Neighbor Index and Nearest Neighbor Hierarchical Clustering

Clark and Evans [79] proposed the nearest neighbor index (NNI) for analyzing the distribution patterns of spatial elements. Unlike Moran's I, NNI does not require data attributes and instead focuses on data aggregation from spatial position [55,56]. The calculation method is the ratio of the actual nearest distance to the theoretical nearest distance [57].

The formula is as follows:

$$\text{NNI} = \frac{d(\text{NN})}{d(\text{ran})} = 2\sqrt{D} \times d(\text{NN}) \tag{1}$$

where NNI is the nearest neighbor index, *d*(NNI) is the average of the distance between the nearest neighbor points, *d*(ran) is the theoretical nearest neighbor distance, and D is the point density. When NNI > 1, it indicates that the elements show a dispersed distribution; when NNI < 1, it means that the elements show an agglomerative distribution. *d*(ran) is calculated as follows:

$$d(\text{ran}) = \frac{1}{2\sqrt{D}} \tag{2}$$

In practice, NNI analysis is followed by nearest neighbor hierarchical clustering (NNHC) to detect element hotspots. NNHC is performed by defining a "limit distance or threshold" for an "aggregation unit" and comparing it with the distance of each spatial point pair. When a point's distance from other points is less than the limiting distance, the point is considered to be an aggregation unit. Accordingly, the original point data is clustered into numerous regions known as first-order hotspot areas. The clusters are formed as second-order hotspot areas using the same method for the first hotspot regions [58,59]. This study applied this technique using Crimestat 3.3 software.

3.2.2. Kriging Interpolation

The Kriging interpolation method is also called the spatial local interpolation method [80]. This is a method for unbiased optimum estimation of regionalized variables in a finite region based on variance function theory and structural analysis, which is one of the main elements of geostatistics [68]. The kriging interpolation analysis not only yields prediction results but also examines the uncertainty of the prediction outcomes. Its calculation formula is:

$$\hat{Z}(s_0) = \sum_{i=1}^{N} \lambda_i Z(s_i) \tag{3}$$

where $Z(s_i)$ is the measured value at the ith position; λ_i is the correlation weight of the measured value; s_0 is the predicted position; and N is the measured value.

3.2.3. Information Entropy Model

The information entropy model is a much commonly used measure in quantifying urbanization functions [66,67]. The magnitude of the entropy value reflects the degree of disorder in the system [60]. Its calculation formula is:

$$\text{Diversity} = -\sum_{i=1}^{n} (p_i \times lnp_i) \tag{4}$$

where Diversity denotes the mixing degree of urbanization functions; n denotes the number of POI categories; and p_i denotes the proportion of a certain type of POI to the total number of POIs in the grid.

3.2.4. Space Syntax

In the 1970s, Hillier and his colleagues introduced the space syntax [81]. Space syntax is primarily used to investigate the relationships between systems and the interactions of elements in spatial structures, including the organizational logic of the spatial form itself and the social logic produced by space [82,83].

Integration, being split into global and local integration, is one of the most common and effective syntactic indicators in urban spatial studies. For urban roads, the higher the degree of local integration, the more central and attractive the road is [70,71]. The connection value indicates the number of additional units that are linked to the unit. The greater a road's connection value is, the greater its accessibility.

3.2.5. Kernel Density Estimation

Kernel density estimation belongs to one of the methods of nonparametric tests [84]. It computes the unit density of element measurements within a given neighborhood. It depicts the distribution of discrete measurements over a continuous area visually [85]. This is calculated by the formula:

$$P_i = \frac{1}{n\pi R^2} \times \sum_{j=1}^{n} K_j \left(1 - \frac{D_{ij}^2}{R^2}\right)^2 \quad (5)$$

where K_j is the weight of study object j; D_{ij} is the distance between spatial point i and study object j; R is the bandwidth of the selected rule region ($D_{ij} < R$); and n is the number of study objects j in the range of bandwidth R.

3.2.6. Buffer Analysis

Buffer analysis is a GIS spatial operation used in urban planning, resource allocation, and other areas of pairs [86]. It refers to the creation of a domain within a certain width based on a given object [85]. In this study, it is used to calculate the number of UR projects within a specified radius of the metro. This is calculated by the formula:

$$B_i = \{x : d(x, O_i) \le R\} \quad (6)$$

where R is the given radius.

3.3. Study Area

Shenzhen, as a pilot area of reform and opening-up, is one of the most competitive, innovative, and influential cities in China. This is also the driving force behind the Greater Bay Area of Guangdong-Hong Kong-Macao. In 40 years, Shenzhen has grown from a modest fishing village to an exceptional national special economic zone. However, the area of Shenzhen is only 1997.47 km^2, of which 1105 km^2 is for construction [87], accounting for only about 50% of the area. Given such limited land resources, Shenzhen is meeting challenges posed by sustainable development [88].

Shenzhen was divided into two areas by the early border management regional line of the Special Administrative Region, namely, the Special Economic Zone area (Luohu, Nanshan, Yantian, and Futian) and the non-Special Economic Zone area (Baoan, Guangming, Longhua, Longgang, Pingshan, and Dapeng) [51]. Disparities in district development have also given birth to a variety of UR issues. In this setting, UR has emerged as a critical means of overcoming urban development impediments. UR is an important component of Shenzhen's urban development [89].

Undoubtedly, the Shenzhen government is more concerned about UR than any other city in China because of the severe challenges it faces [31]. Currently, Shenzhen is not only the largest city in China in terms of UR scale but also the most pioneering metropolis in UR policymaking. Shenzhen's experience and insights can help other cities perform UR in a meaningful way. Thereby, Shenzhen was chosen as a case study city in this study.

3.4. Materials

The first section of this research investigates the spatial characteristics of UR projects using NNI and NNHC. This study crawled all the data of the implemented UR projects released by Shenzhen UR Network in March 2021 by Python for this aim. According to the official classification, UR projects are classified into five types: urban villages, old industrial, old commercial, old residential, and mixed-use areas.

The second part analyzes the spatial distribution characteristics of UR by using several representative urbanization development indicators as illustrated above. The data about the metro system is extracted from the Amap using Python and Arcgis (only includes metro lines in use). Urban population data were obtained from Baidu Map mobile, and the population heat map was captured in July 2021. It was captured by Python and then imported into ArcGIS for heat grading, with population heat values ranging from 1 to 7.

The housing prices are reflected by the average prices of different residential neighborhoods reported on the Lianjia official webpage in July 2021 and captured by Python. POI's information entropy model was used to quantify urbanization functions. The POI data from Amap were crawled using Python in February 2021, resulting in a total of 790,000 pieces of valid data. Based on the 14-category classification system of Amap POI data, this paper further summarizes them into six major categories: living services, public services, business, leisure and entertainment, residence, and finance and insurance to facilitate the calculation of the information entropy model.

The urbanization form is characterized by density partitions and road network system. The road network system is gained from the National Geographic Information Resource Catalogue Service System. The density partition map is obtained from the portal of the Shenzhen Municipal Government. This is visualized and analyzed through GIS rasterization. The websites of data sources are shown in Table 2.

Table 2. Data sources.

Data	Source	URL
UR Projects	Shenzhen UR Projects Information	http://csgx.szhome.com/ (accessed on 24 March 2021)
Road Network	National Catalogue Service for Geographic Information	https://www.webmap.cn/main.do?method=index (accessed on 14 July 2021)
Density Partition of Built-up area	Portal of Shenzhen Municipal Government	http://www.sz.gov.cn/cn/xxgk/zfxxgj/zcfg/szsfg/content/post_6580490.html (accessed on 18 July 2021)
House Prices	Lianjia official portal	https://sz.lianjia.com/xiaoqu/cro21/ (accessed on 15 July 2021)
Metro	Amap	https://www.amap.com/ (accessed on 12 February 2021)
POI		
Population Heat Map	Baidu Maps	https://map.baidu.com/@11854652,3430240,13z (accessed on 18 July 2021)

4. Results

4.1. Spatial and Temporal Distribution Characteristics of UR

The overall distribution of UR projects (Appendix A, Figure A1) demonstrates the characteristics of "global concentration and local dispersion". It means that the projects are concentrated in a specific position in each region, such as the central part of Longhua District, the western and central part of Longgang District, the southern and northern part of Baoan District. However, they are scattered in these regions.

To gain a better insight of the overall distribution of UR projects in Shenzhen, the kernel density was evaluated after the obtained area elements were transformed into point elements, as shown in Figure 2. The figure depicts significant disparities in the number of UR projects in Shenzhen among different regions, which primarily reflects a pattern of spreading outward from the district centers.

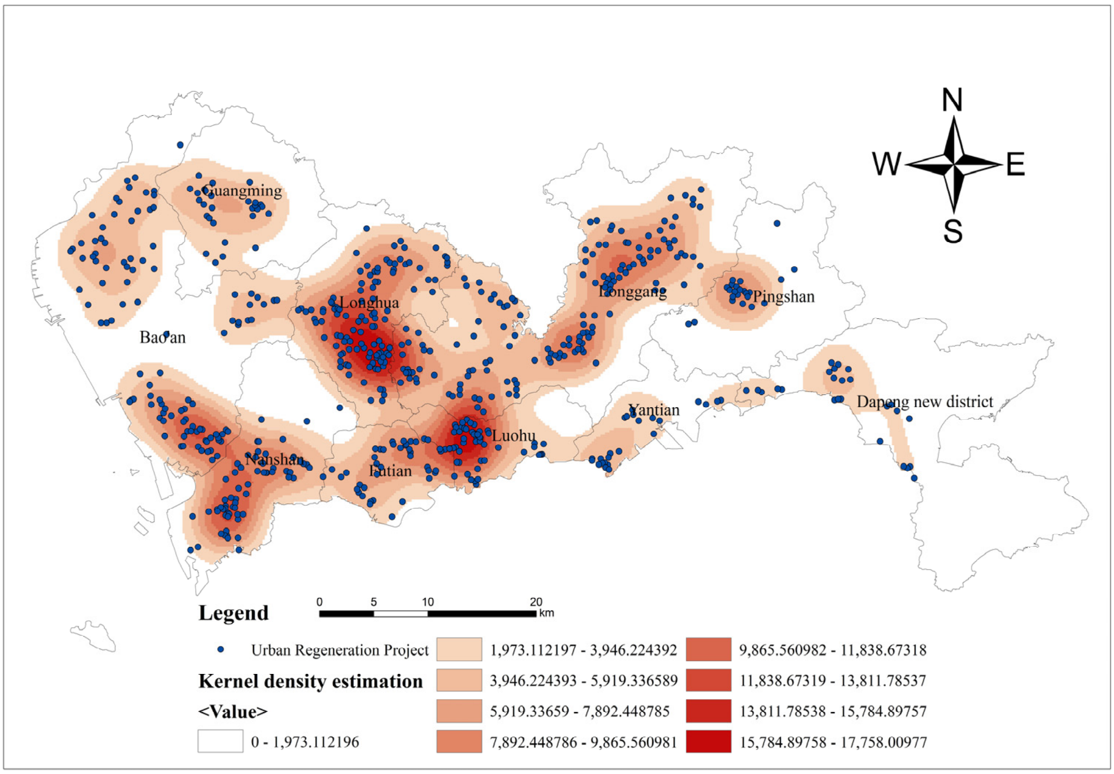


Figure 2. Shenzhen UR kernel density estimation.

The UR projects are mainly concentrated in streets, such as Dongxiao, Dongmen, Zhugang, and Cuijhu in Luohu District, as well as Longhua and Minzhi streets in Longhua District, the western part of Nanshan District, the southern part of Baoan District, and the central part of Longgang District. These areas are defined as early warning areas of development capacity saturation in the "Thirteenth Five-Year Plan for UR in Shenzhen".

The spatial clustering trend of the projects was further tested by using Equations (1) and (2). The results show that the NNI of UR projects in Shenzhen are all less than 1. Apart from the mixed-used area, the p values of other types of projects are less than 0.01, which meets the significance test (Table 3). According to the calculation results, the NNI of several types of UR projects fluctuates above and below 0.6 with little variation, indicating that their clustering degree is similar and that they all reflect the trend of the agglomeration distribution in space.

Table 3. NNI of UR projects.

Type	Sample Size	Observation Distance/m	Expectation Distance/m	NNI	z-Value	p-Value	Distribution Type
All	620	560.7595	893.23833	0.627783	−17.7306	0	Agglomeration
UV	229	919.6744	1469.75672	0.625732	−10.835	0	Agglomeration
OI	292	802.2145	1301.582707	0.616338	−12.5421	0	Agglomeration
OC	53	1731.234	3055.098809	0.56667	−6.03514	0	Agglomeration
OR	35	2892.054	3759.492074	0.769267	−2.61141	0.009017	Agglomeration
MU	11	5644.881	6706.051019	0.841759	−1.00403	0.315366	Agglomeration

Note: UV = urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

NNHC analysis was conducted to obtain the hotspot areas formed by the clustering of different types of UR projects in Shenzhen (Appendix B, Figure A2). Overall, the distribution of the first-order and second-order hotspots formed by different types of UR projects is different in the whole city.

To sum up, Shenzhen contains 32 first-order hotspots and three second-order hotspots. The distribution of first-order hotspots is fairly scattered, with several hotspots in each district. In Longhua, Luohu district, the southern part of Baoan district, and the western part of Nanshan district, the distribution of second-order hotspots is similar to the results of kernel density estimation. The spatial distribution is structured as a multi-center agglomeration distribution.

These hotspots are also Shenzhen neighborhoods that have evolved earlier or have swiftly transformed their industry structure, such as Shootang, Dongxiao, and Longhua streets. Regarding to urban villages projects, it shows that there are nine first-order hotspots and one second-order hotspot. The first-order hotspots are mostly concentrated in Shenzhen's north, with Longgang District holding the most first-order hotspots, where the second-order hotspots form. Old industrial area projects are mostly located in Shenzhen's central and western regions, including Baoan and Longhua.

There are 15 first-order hotspots and one second-order hotspot, among which the second-order hot spots are distributed in Longhua District. By comparison, it is found that these hotspots are the key construction areas in Shenzhen during the 13th Five-Year Plan period, including Banxuegang Science and Technology City, Dakonggang New City, Guangming Phoenix City, Sungang Qingshuihe Area, and North High-tech Zone. Old commercial area projects are mainly distributed in the southwest of Shenzhen, forming four first-order hotspots. These hotspots are also distributed in the planned main and sub-centers of Shenzhen, including Qianhai Center, Futian-Luohu Center, and Airport Center.

The sorts of UR projects conducted in various years are diverse (Table 4). Before 2010, urban villages were mainly implemented, and then the number of projects began to fall, while the share of old industrial areas climbed year by year. When combined with the spatial distribution map (Appendix C, Figure A3), it is clear that the early UR projects were concentrated in the Special Economic Zone and district centers.

Table 4. Development of UR projects in each year.

Type	Before 2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
UV	87	8	19	9	14	26	20	1	14	21	10	0	229
OI	38	37	30	9	25	33	28	6	43	26	16	1	292
OC	11	5	6	6	7	5	1	1	7	2	2	0	53
OR	10	3	3	1	1	0	2	1	9	0	4	1	35
MU	4	1	3	2	0	0	1	0	0	0	0	0	11
Total	150	54	61	27	47	64	52	9	73	49	32	2	620

Note: UV = urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

However, the distribution of projects gradually expands outward as time goes by. As observed from the perspective of the land use function transformation (Appendix D, Figure A4), no matter which type of UR projects they were, the residential or commercial land is the major land use change orientation. The industrial land mainly comes from old industrial area projects.

For kernel density estimation, dividing the scale of UR projects into three categories, it reveals that the scale of UR projects in Shenzhen mainly ranges from 10,000 to 100,000 m^2 (Table 5 and Appendix E and Figure A5). Smaller projects (less than 50,000 m^2) are mainly distributed in the Special Economic Zone and the central areas of districts. Projects with large areas (greater than 100,000 m^2) are mainly distributed in the urban fringe areas.

Table 5. Number of UR projects of different scales.

Types	OI	UV	OR	OC	MU	Total	Proportion
less than 50,000 m^2	176	71	17	37	1	302	49.11%
between 50,000 and 100,000 m^2	62	69	14	10	3	158	25.69%
larger than 100,000 m^2	51	87	4	6	7	155	25.20%
Total	289	227	35	53	11	615	100%

Note: UV = urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

4.2. The Relationship between Public Transportation and the Distribution of UR Projects

Figure 3 demonstrates that UR projects in Shenzhen present characteristics of clustering distribution along the metro line. According to the radiation distance along the metro line, 500 and 1000 m buffer zones are set respectively. As shown in Table 6, the number of UR projects located within the 1000 m radius of the metro is 379, accounting for 61.1% of all projects.

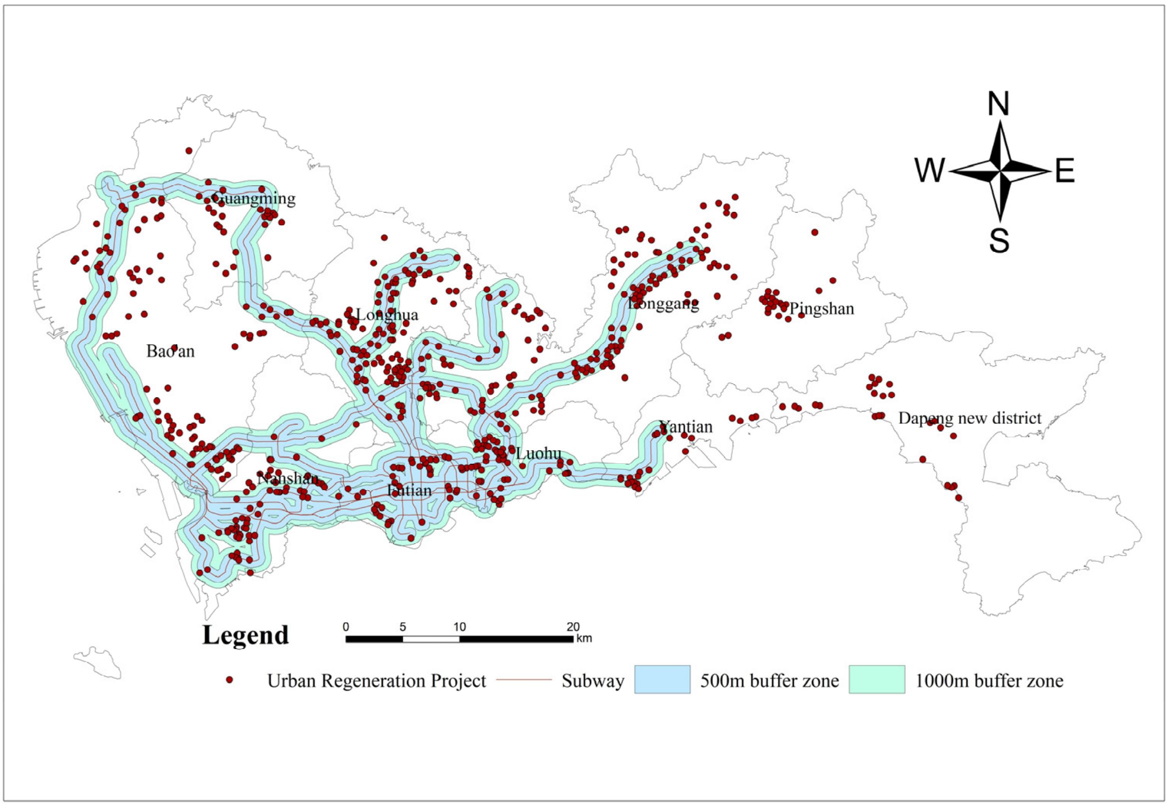


Figure 3. Distribution of UR along the metro.

Table 6. Number of UR projects in the metro buffer zone.

Types	Total	500 m	Percentage	1000 m	Percentage
UV	229	75	33%	133	58%
OI	292	112	38%	171	59%
OC	53	29	55%	38	72%
OR	35	18	51%	28	80%
MU	11	7	64%	9	82%
Total	620	241	38.9%	379	61.1%

Note: UV = urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

The number of UR projects located within a 500 m radius of the metro is 241, accounting for 38.9% of all projects. Old commercial area and old residential area account for a higher proportion of UR projects within the metro buffer zones than other types. Simultaneously, compared with the rail transportation planning map, the majority of the remaining projects are distributed near the rail lines under construction, including Line 8 Phase II, Line 11, Line 16, and Line 14 Pingshan Branch and Longgang Branch.

4.3. The Relationship between the Urban Population and the Distribution of UR Projects

In Shenzhen, there is a substantial correlation between the distribution of UR projects and population density. As demonstrated in Table 7 and Figure 4, UR projects are primarily distributed in areas with a population heat value greater than 4, with 496 UR projects. The majority of the projects are centered in locations with a population heat value of 6–7, implying a population density of 40 people per square decimeter. This demonstrates that higher population density regions are more likely to apply UR.

Table 7. Number of UR projects with different population heat values.

Heat Value Classification	Total	UV	OI	OC	OR	MU
0	3	1	2	0	0	0
1	57	26	27	2	2	0
2	16	7	9	0	0	0
3	48	20	23	3	2	0
4	63	27	30	4	1	1
5	57	22	32	1	1	1
6	143	46	72	14	7	4
7	233	80	97	29	22	5
Total	620	229	292	53	35	11

Note: UV = urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

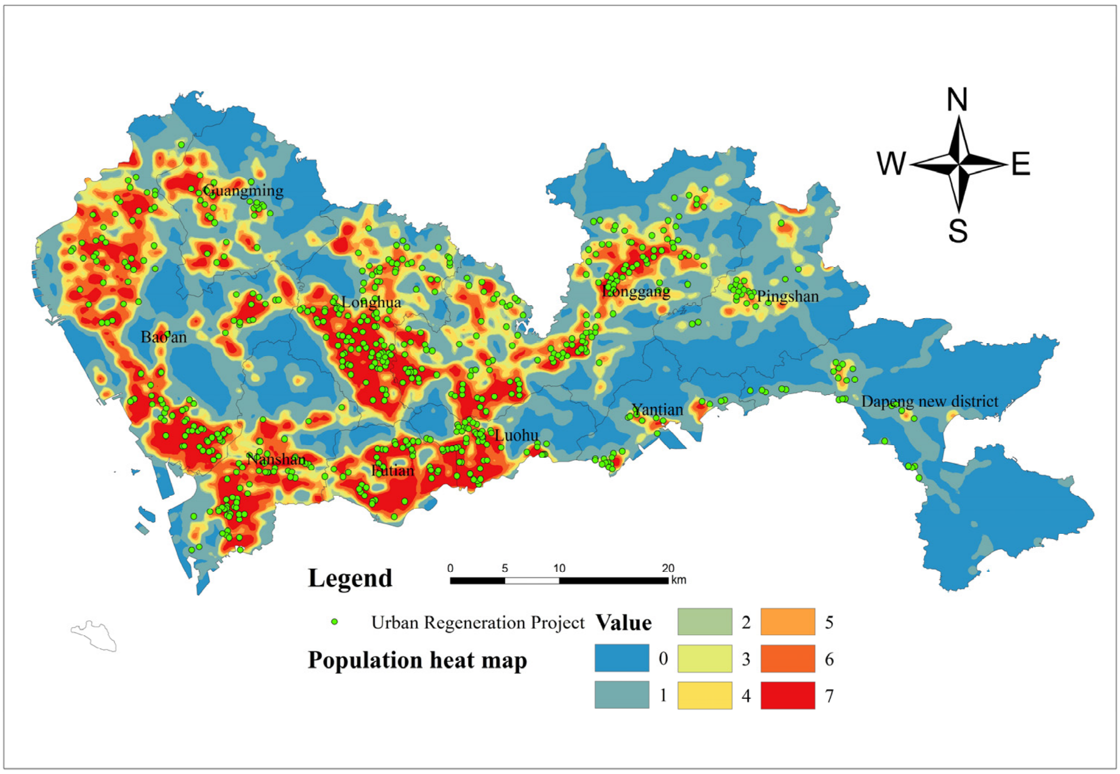
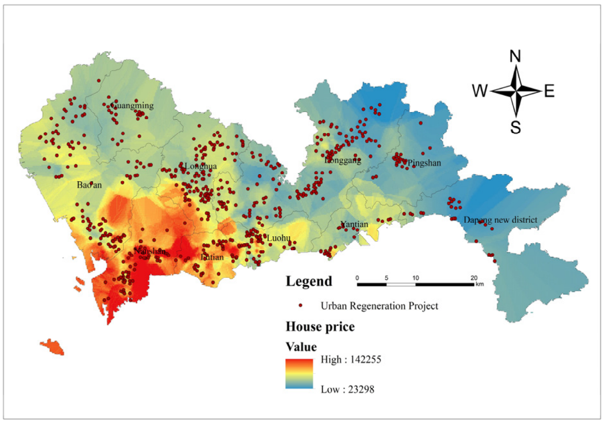


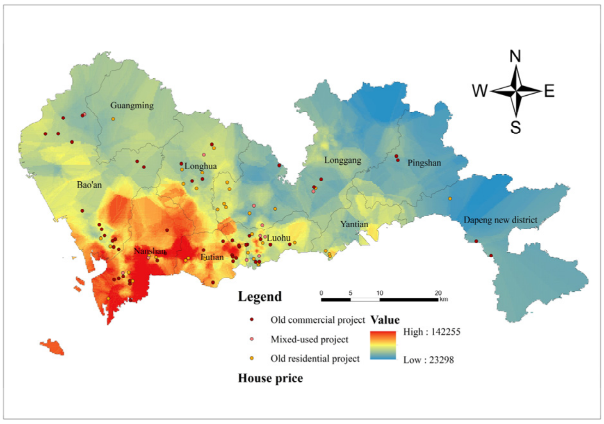
Figure 4. UR and population heat map.

4.4. The Relationship between House Price and the Distribution of UR Projects

Since the house price data is normally distributed, kriging interpolation can be conducted. The results are revealed in Figure 5 and Table 8, illustrating that the house price in Shenzhen is decreasing from southwest to northeast in space (Figure 5a and Table 8). UR projects are mostly situated in locations with average home prices of more exceeding 40,000 yuan. On the other hand, the influence of housing prices on the distribution of UR is not evident. UR projects are evenly dispersed in both affluent and low-income neighborhoods. Further examination of past commercial and mixed-use area developments reveals that they will be allocated in regions with higher housing prices



(**a**)



(**b**)

Figure 5. Distribution of UR and house prices: (**a**) all UR projects and (**b**) OC, MU, and OR projects.

Table 8. Number of UR projects in different house price ranges.

House Price	All	UV	OI	OC	OR	MU
Over 40,000	474	144	246	45	30	9
Less than 40,000	146	85	46	8	5	2
Total	620	229	292	53	35	11

Note: UV = urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

4.5. The Relationship between Urbanization Function and the Distribution of UR Projects

The information entropy model is established to quantify the POI mixing degree in Shenzhen. Figure 6 depicts that UR projects in Shenzhen are primarily concentrated in areas with a high POI mixing degree, i.e., areas with perfect urbanization functions, such as the north and south of Baoan District, the center of Longgang District, Nanshan District, Futian District, Luohu District, and Longhua District. In the population heat map, it can be found that the areas with well-developed urbanization functions also have a high density of population, which mutually confirms the distribution characteristics of UR projects.

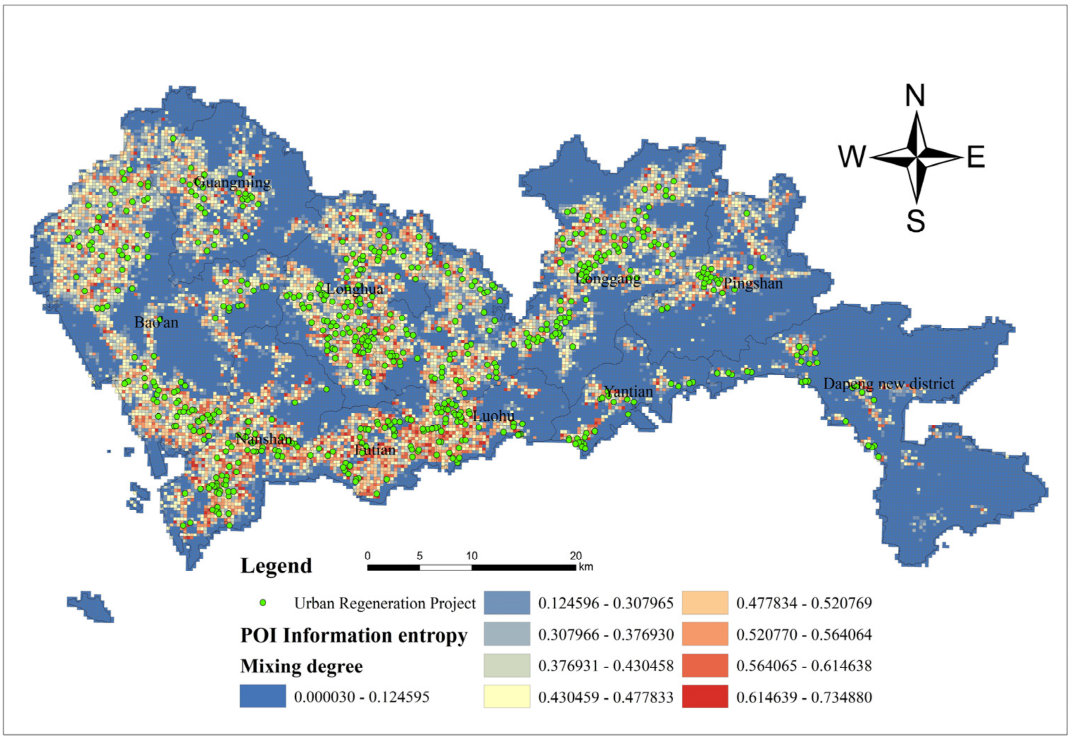
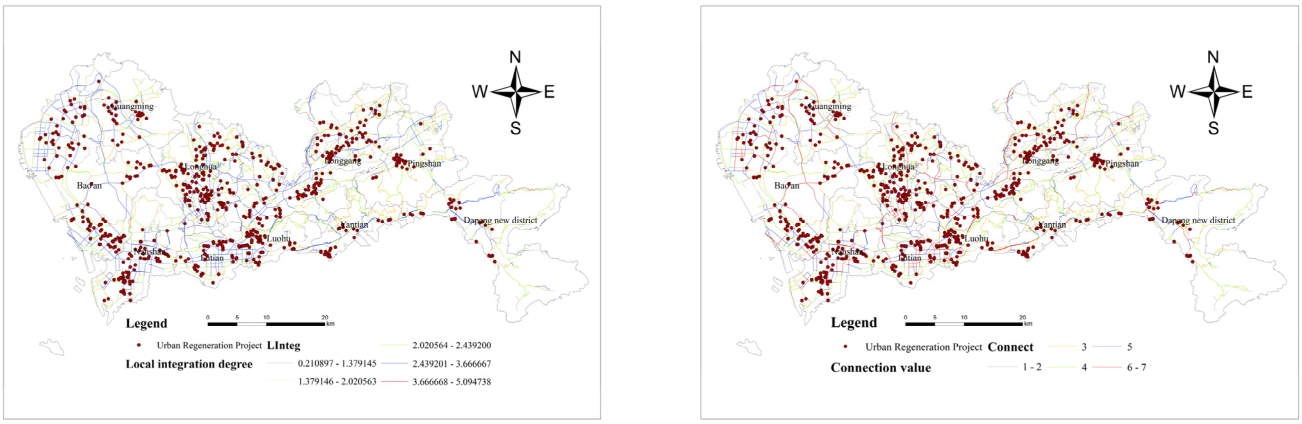


Figure 6. UR and POI mixing degree.

4.6. The Relationship between Urbanization Form and the Distribution of UR Projects

As an integral part of the urban fabric, the transportation network is closely related to urbanization development. As depicted in Figure 7, using the space syntax to calculate the connection value and integration degree of urban roads, the following characteristics are revealed: (1) UR projects in Shenzhen are mainly distributed along with the transportation network; (2) UR projects are distributed in areas with high connection value—that is, in areas with good spatial accessibility; and (3) UR projects are distributed in areas with high local integration—that is, in areas with high spatial attraction.



(**a**) (**b**)

Figure 7. UR and Spatial Syntax Map: (**a**) local integration and (**b**) connection.

As shown in Figure 8, by combining the density zoning of urban planning in Shenzhen and the distribution of UR projects, it can be found that UR projects are concentrated in areas with higher allowed development intensity, mainly in density zones 1 to 3. However, there are also a few projects in density zones 4 to 5.

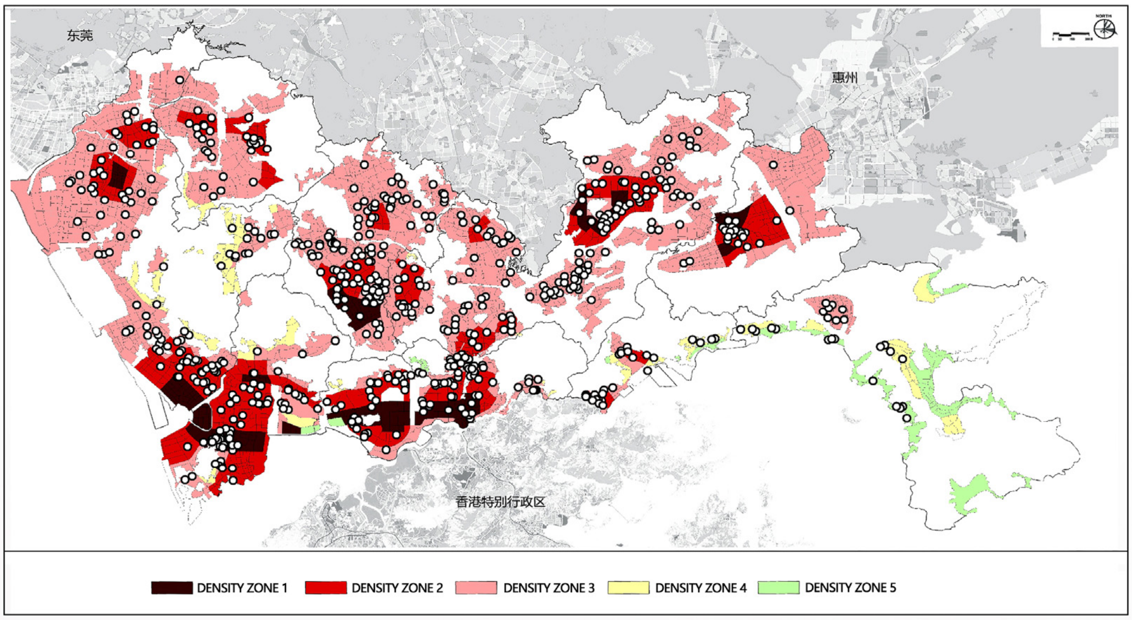


Figure 8. Shenzhen UR and construction land density zoning map.

5. Discussions

5.1. The Mixed Methods for Analyzing Spatial Distribution Characteristics of UR in Shenzhen

This research clearly shows that combining NNI, NNHC, kernel density estimation, kriging interpolation, information entropy model, and space syntax can comprehensively reveal the spatial distribution characteristics of UR projects in Shenzhen. Through GIS, these mixed methods can spatially display information on the spatial location, geographical form, and changing geographic objects [90].

This research adopted GIS as the analytical tool, showing that the UR projects in Shenzhen are mostly located in areas experiencing industrial restructuring and severe urban decay. Urban villages in Shenzhen are mainly located in the non-Special Economic Zone due to its setting of the Special Economic Zone (SEZ) borderline previously. Due to its proximity to Hong Kong and Macau, the SEZ can easily attract investment and can capitalize on additional development potential, leading considerable flocks of mainland people who seek decent employment.

That said, a large amount of people still failed to relocate in the SEZ, thus, congregating outside the SEZ in the districts of Baoan and Longgang. Following the urbanization of non-SEZ in 2004, these residential-concentrated areas transformed into a large number of urban villages located in rural land surrounded by urban land [51]. In the same period, Shenzhen's modern service industry developed rapidly, with vast stretches of industrial land gradually converting to commercial land.

Numerous industrial relocation occurred in districts outside SEZ, such as Luohu and Futian. As a result, many old industrial areas have been clustered in Baoan, Longhua, and other districts. With today's rapid urbanization, these districts are confronting the needs for urban environment improvement and industrial upgrading. Therefore, conducting UR projects in certain old industrial areas has been favored [91].

Corroborated by this study's findings, UR projects are mostly conducted in the areas with a better urban economy and accessibility [92–94]. The transportation network serves as the city's "economic artery." Throughout the city's history, most of the industrial structures, commercial hubs, and neighborhoods have been developed alongside the transit network. Today, Shenzhen's low-level manufacturing, wholesale trade, and old residential buildings situated along the transportation network can no longer satisfy the demands of future new industries and urban development. These areas are characterized by high land value, large population, and diverse urban functions.

Thus, the decision-makers and investors are prone to designate these areas to conduct UR projects [37]. Indeed, the distribution of UR projects in Shenzhen reveals a distinct preference for economic value. Nonetheless, sustainable UR necessitates consideration of social and environmental factors, which are currently absent in Shenzhen's UR practices.

5.2. The Combination of Top-Down and Market-Driven UR Approaches

According to the analytical results of space syntax, population heat map, buffer analysis, and information entropy model, the preference for market power demonstrates a major impact on UR implementation. The characteristics of UR distribution in Shenzhen are closely linked to the transportation network, population, and the spectrum of urban functions. Based on the spatial visualization, large-scale projects are shown to be mainly located on the outskirts of cities. Longgang, in particular, has a higher rate of urban village project implementation than Baoan, owing to Baoan's more concentrated display and its ensuing higher regeneration costs. Due to the financial needs and risk concerns, developers prefer small-scale projects in a decent location with higher land value under such conditions [51,95].

Market power intervention in UR also had severe unexpected repercussions, such as over-commercialization and over-homogenization. Over-commercialization may easily lead to the disregard of urban space's fundamental value. In practice, the demolition of existing buildings in their early stages of service is common [96]. This not only undermines social equity but also implies the waste of resources and excessive carbon emissions.

Furthermore, over-commercialization may hinder urban growth since high housing and living costs lead to population loss and gentrification, reducing cities' vibrancy. In terms of over-homogenization, this results in the loss of urban diversity [32,97]. To reduce the costs, developers tend to adopt similar or even identical designs, materials, and standards in different projects. In some aspects, UR has become a streamlined "factory" for reshaping social space. Similar products are frequently produced via redevelopment. This practice obliterates urban texture, culture, and diversity.

In Shenzhen's case, through kriging interpolation analysis, it is surprising to discover that the spatial distribution characteristics of UR demonstrate an un-correlated relationship with housing prices. This indicates that market power is not entirely dominating in UR. Moreover, most UR projects are not only distributed in density zones 1 to 3; many of them are also located in density zones 4 and 5. This implies that government intervention is also prominent in promoting UR projects [91].

Although the top-down method has been shown to be an effective way to improve urban living environments, it is almost impossible for the government to sustainably dominate most of the UR projects [98]. However, the top-down approach also implies government investment, particularly for UR initiatives without demolition and new buildings. Some projects are difficult to accomplish due to a lack of market investment.

If developers dominate the project, it is designated as "private goods" with commercial benefits. The current UR theories and policies in China cannot effectively facilitate the development and management of private ventures [99]. New challenges have thus been generated for attracting investments in less profitable projects and barriers to the government's policymaking and financial control in cooperating with market power.

To avoid the challenges produced by top-down and market-driven UR approaches, it is critical to establish a post-assessment mechanism and efficient UR feedback loops. A dual mechanism integrating bottom-up and top-down information distribution platforms is also necessary for policy interpretation and public opinion collection. Furthermore, soliciting in-situ residents' willingness to pay and focusing more on profits in post-operation (i.e., community services and property management) are successful methods for long-term UR.

5.3. Dilemma of the Center-Periphery Model in UR Implementation

Based on Krugman's Center-Periphery Theory [100], urban development is generally spread from central to peripheric urban area through the urban sprawl. Comparing to the peripheric area, the central area holds the priority of obtaining better social and economic resources [101]. This is a global phenomenon. The prior development of the central urban area, in many cases, can also effectively benefit the improvement of the peripheric urban area, which is a wide consensus in the field of urban sprawl [101,102].

The center-periphery concept is clearly observed in UR implementation based on the spatial distribution of UR projects throughout time. However, when compared to urban sprawl, the UR is a completely different pair of shoes. Many negative outcomes are alleged to have occurred due to the excessive number of UR projects implemented in the central urban area and their uneven distribution on the city scale. The real estate market and the local living environment affect the cost of UR.

In a short amount of time, concentrating UR initiatives in a certain location may cause a rise in housing prices and an improvement in the living environment. Under this condition, implementing UR projects in this area will be much more costly, posing more difficulties for further promoting UR in a holistic view [28]. In practice, some projects were stalled in the stagnation due to the growing expenditure (e.g., the increasing requirement of in-situ residents) brought by the implementation of surrounding projects. This situation creates a "reverse" effect in urban planning and design.

To address the issues, the equity and transparency of the UR process must be enhanced by establishing a set of UR systems at various administrative levels. A unified standard for designating UR areas is desperately needed. This should incorporate the UR cost-efficiency principle, thereby, highlighting the orderly identification and implementation of UR projects.

5.4. Barriers of the Industrial Clustering Formation

Although Shenzhen has implemented considerable UR projects per year, the findings of the NNHC analysis indicates that the distribution of UR projects on the district scale is quite fragmented, regardless of the time factor. This trait makes it difficult to promote project implementation using a project portfolio strategy, which significantly diminishes the spatial guidance effect of industrial planning.

Industrial cluster development is an essential technique for forming the urban competitive advantage, as proposed in growth pole theory and new competitive advantage theory [103,104]. Shenzhen pays great attention to the joint development of innovative industries clusters (Appendix F, Figure A6) [87]. Based on the distribution of UR projects each year and land-use change analysis, the proportion of UR projects for the industrial area is marginally increased in recent years. Nonetheless, most of the implemented old industrial areas have changed to residential or commercial lands [91].

This is likely due to the drawbacks of the current institution, which cannot effectively coordinate industrial planning and UR planning. Moreover, in view of project scale, the areas of old industrial projects in Shenzhen ranges mainly from 10,000 to 100,000 m^2. Given the scarcity of urban land for new development, these projects can be regarded all of the newly supplied industrial development projects. According to the two theories stated above, restricted industrial land and scattered small-scale old industrial area regeneration cannot help form industrial clusters or improve urban competitive advantage.

To overcome the above barriers, industrial planning ought to be well-coordinated with UR planning. It is beneficial for the government and investors to jointly consider the types of industrial clustering on a broader scale, thus, applying UR to better promote the transformation and upgrading of old industrial lands.

5.5. Paradox between the Growing Population and the Limited Undeveloped Urban Land

The distribution of UR projects is significantly related to the density of the urban population, as seen in the population heat map. Indeed, implementing UR projects in densely populated area is critical for improving the living quality of the most urban population. In practice, UR is not merely for improving the well-being of existing citizens. The housing issues of the new population should also be taken into consideration. According to the statistics, Shenzhen has added over 7.13 million urban population in recent decades, also accounting for an astonishing number worldwide [105]. The rapid growth of the urban population has not only promoted Shenzhen's urban vitality but also raised the paradox between the growing population and the limited undeveloped urban land.

In Shenzhen, the proportion of construction land has long reached 50%, exceeding the alert line of international urban development intensity [106]. Due to the lack of new land development, the growing population is mainly concentrated in the existing urban area, resulting in huge additional housing demands.

Under this situation, the housing supply is considerably increased through UR. This increase not only relies on the growth of plot ratio through the regeneration of existing neighborhoods but also the change of land use from another land to residential land. The massive increase in housing supply in old urban areas results in the constant challenges of urban carrying capacity [29]. Adopting UR without enhancing the quality and quantity of adequate infrastructures may eventually affect the overall living environment.

As can be seen, the UR in commercial land also accounts for a large proportion of the whole. Moreover, its spatial agglomeration degree is relatively high. Commercial clustering can also contribute to population clustering and thus pose more challenges for urban carrying capacity. Simultaneously, the vacancy rate of office buildings in Shenzhen has exceeded 25% [107]. In many circumstances, providing too many commercial projects produces the hollowing-out problem, resulting in inefficient land use and waste of urban resources [108].

To break the paradox, changing the values from the past economic efficiency-led to the sustainable and people-oriented is of great importance. It is essential to coordinate the UR and urban population planning by making full use of big data, GIS, and other state-of-the-art methods. In addition, utilizing the urban vertical space can be considered in UR.

6. Conclusions

This paper revealed that the distribution of UR projects in Shenzhen meets the requirements of urban development through spatial characteristic analysis. Based on all the officially released data of implemented UR projects between 2010 and 2021, this paper used the NNI, NNHC, and kernel density estimation for spatio-temporal analysis considering the data structure. Then, mixed methods (i.e., buffer analysis, space syntax, and heat map) were utilized to quantify and visualize the influence of urbanization development level on the distribution of UR projects.

The study identified a trend of "global concentration and local dispersion" in the distribution of UR projects. The NNI also further revealed the agglomeration of UR. NNHC showed that different types of projects are spatially distributed in different hotspots. Urban village projects are mainly concentrated in Longgang, and old industrial area projects are mainly concentrated in Longhua.

The results of the mixed methods revealed that the UR projects in Shenzhen are mostly located in areas experiencing industrial restructuring and severe urban decay. This is strongly related to the history of Shenzhen's development. In addition, we demonstrated that UR projects are mostly conducted in areas with a better economy and accessibility. This is in line with the ideology of pursuing market value in urban development.

However, apart from economic benefits, the sustainable UR necessitates attention to social and environmental dimensions, which are undervalued in current Shenzhen UR practices. Over-commercialization and over-homogenization occur due to market power domination.

However, the substantial involvement of the top-down approach may pose new challenges in attracting investments in less profitable projects, as well as impediments to the government's policymaking and financial control. In UR implementation, the practice of the center-periphery model generates a "reverse" effect in urban planning and design. The barriers of the industrial clustering formation and the paradox between the growing population and the limited undeveloped urban land are uncovered accordingly. This poses challenges to the urban spatial carrying capacity and weakens the city's competitiveness.

The contributions of this study are threefold. First, it fills a research gap by conducting an empirical analysis of UR in China on a city-wide scale. We examined the patterns of UR project distribution from multiple dimensions, including space, time, and scale. Secondly, by adopting ArcGIS tools, this study performed kernel density estimation, mean nearest neighbor index analysis, and kriging interpolation analysis. For space syntax analysis and nearest neighbor hierarchical clustering analysis, the Deth map and Crimestat 3.3 were utilized, respectively.

Compared with other studies that explored spatial distribution only by using one or two methods, this study is more comprehensive and convincing in reflecting spatial features, which can provide methodological reference for spatial and visualization studies of UR in other cities globally. Thirdly, this study revealed the current UR problems through spatial characteristic analysis. Using the case of Shenzhen, it can provide an in-depth understanding of the UR.

This sheds light on how to promote UR and meet the requirements of sustainability on the city scale and deliver implications for other Chinese cities for future urban development. The dilemma of the center-periphery paradigm in UR implementation, as well as the over-commercialization and over-homogenization generated by UR, as highlighted in this paper, must be brought to the attention of other cities worldwide. The paradox between expanding population and limited undeveloped urban land has long been a global issue.

This study has several drawbacks as well. The selection of urban development indicators is mostly based on literature and data, which are insufficiently comprehensive. Future research might look into enriching the index system and data sources. Second, some indicators, such as the rate of UR implementation, are useful in analyzing present UR issues. However, owing to data accessibility, several valuable indicators were not provided in this study. It would be advantageous to collect and evaluate them further in future research.

Author Contributions: Conceptualization, T.Z. and G.L.; methodology, C.L.; software, C.L.; validation, T.Z., G.L. and C.L.; formal analysis, C.L.; investigation, C.L. and J.T.; resources, C.L.; data curation, C.L. and H.W.; writing—original draft preparation, T.Z. and C.L.; writing—review and editing, H.W. and Y.Z.; visualization, C.L.; supervision, G.L.; project administration, T.Z.; funding acquisition, T.Z. and G.L. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all individual participants included in the study.

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.

Appendix A

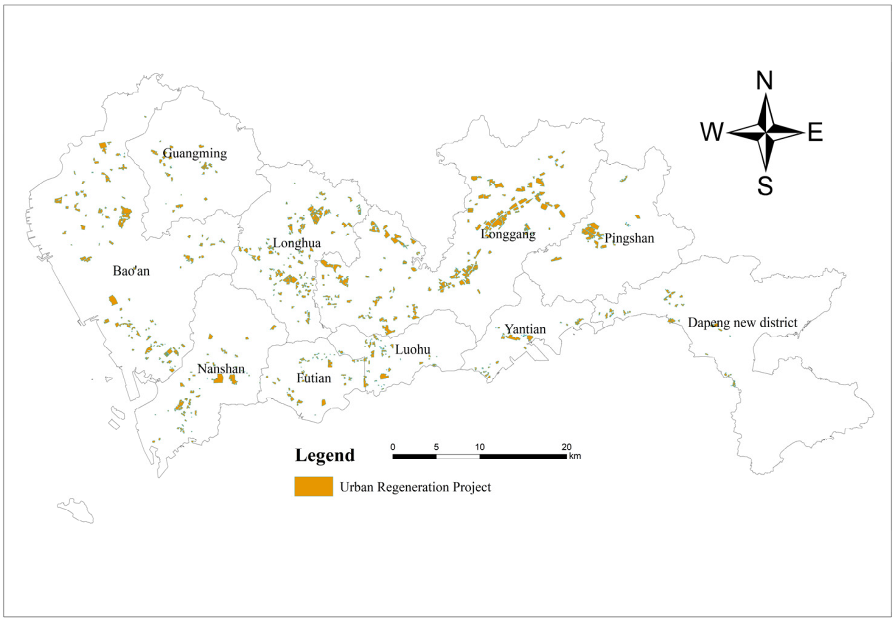
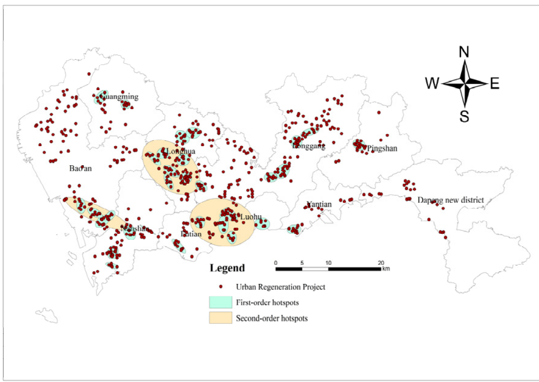


Figure A1. Spatial distribution of UR in Shenzhen.

Appendix B



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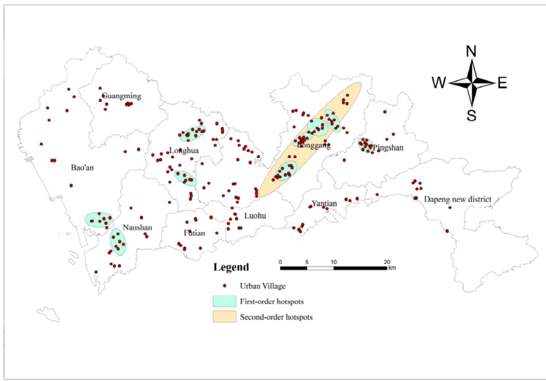

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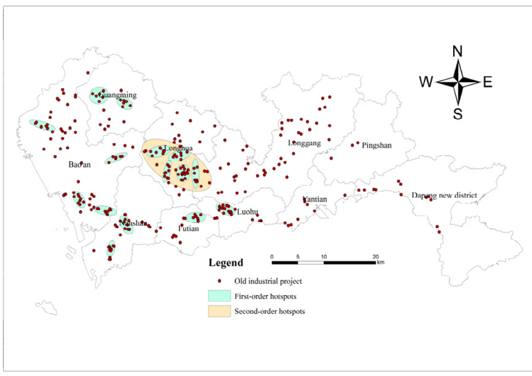

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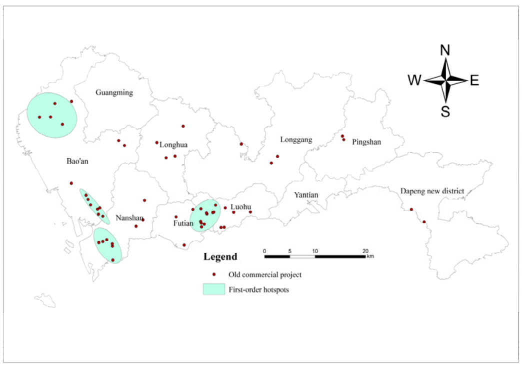
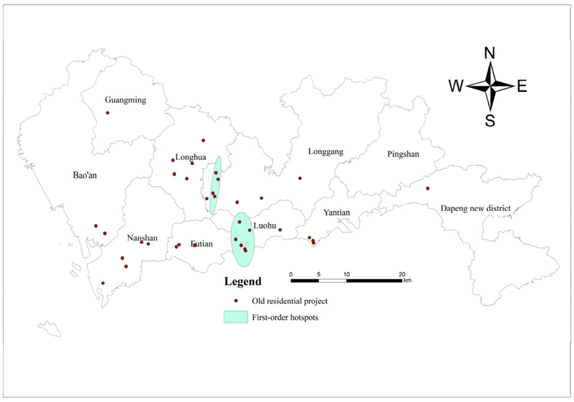


(**d**)

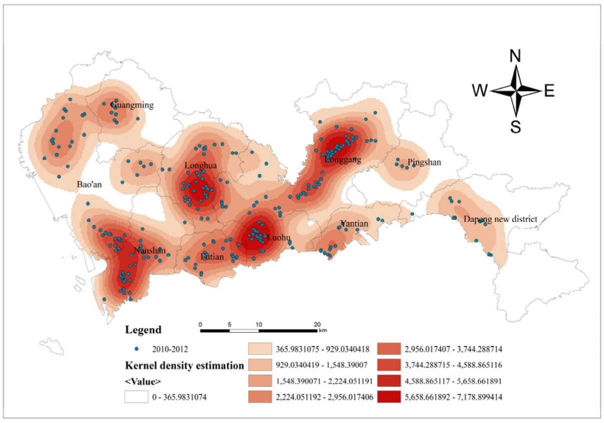
Figure A2. *Cont.*



(**e**)

Figure A2. Spatial Distribution of UR Hotspot Cluster Areas: (**a**) all UR projects; (**b**) urban village projects; (**c**) old industrial projects; (**d**) old commercial projects; and (**e**) old residential projects.

Appendix C



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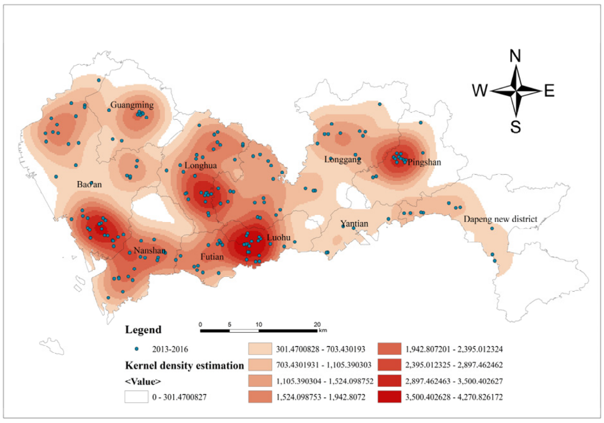

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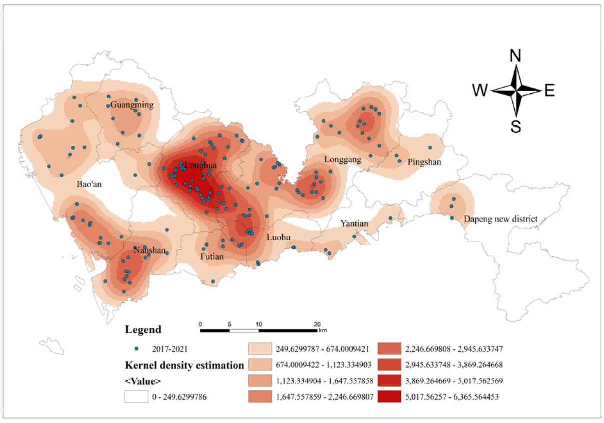


(**c**)

Figure A3. The distribution of UR projects in different years: (**a**) 2010–2012; (**b**) 2013–2016; and (**c**) 2017–2021.

Appendix D

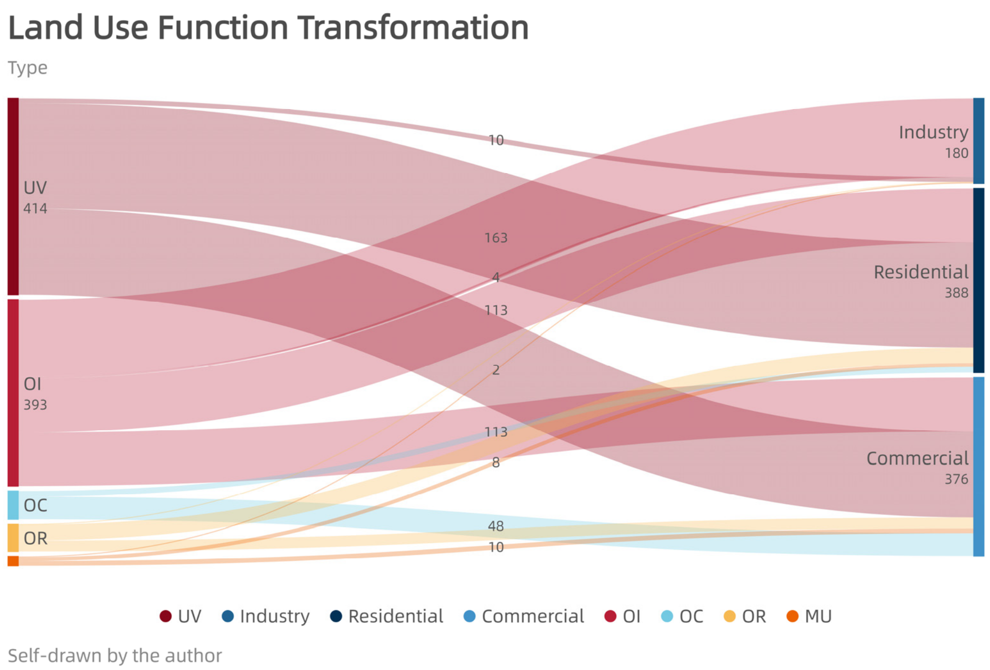
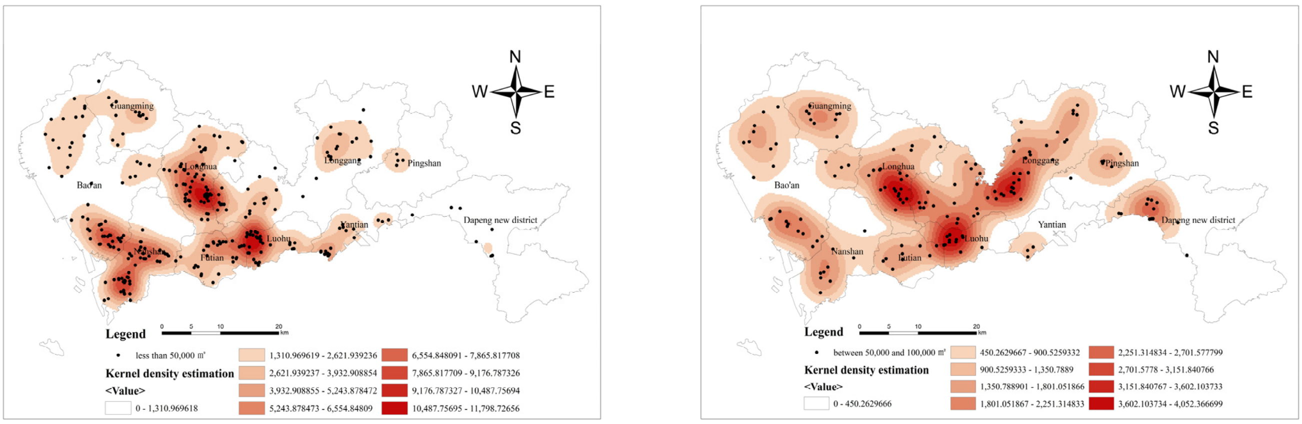


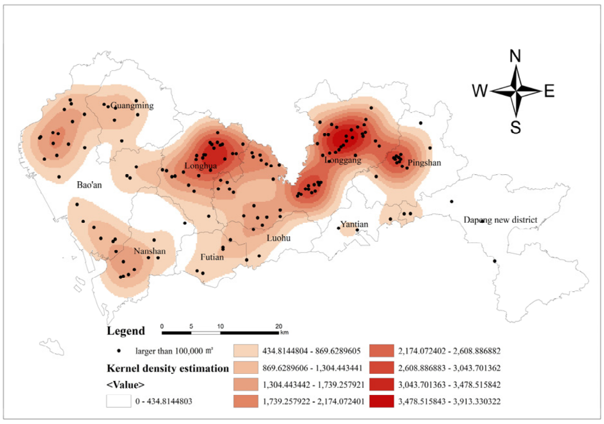
Figure A4. Land use change of implemented UR projects in Shenzhen. UV= urban villages, OI = old industrial area, OC = old commercial area, OR = old residential area, and MU = mixed-used area.

Appendix E



(**a**) (**b**)

Figure A5. *Cont*.



(**c**)

Figure A5. Spatial distribution of UR of different scales: (**a**) less than 50,000 m^2; (**b**) between 50,000 and 100,000 m^2; and (**c**) larger than 100,000 m^2.

Appendix F

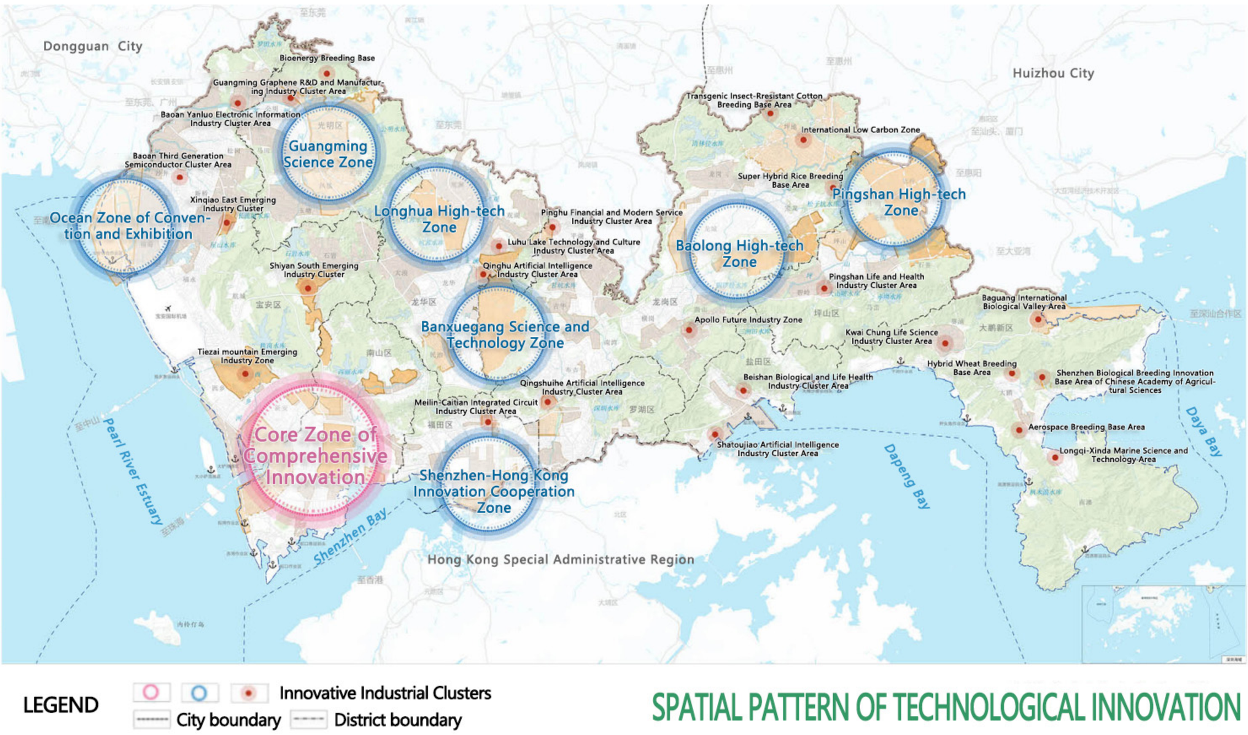


Figure A6. Shenzhen Innovation Industry Cluster.

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