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Planning for Sustainable Urban and Land Development, Second Edition

Edited by
Zongcai Wei, Yuting Liu and Andrzej Biłozor

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Guest Editors

Zongcai Wei
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Andrzej Biłozor

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Article

Research on the Evolutionary Characteristics of Innovation Space and Influencing Factors Based on Patent Data—Harbin as an Example

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Abstract: Innovation is the core driving force behind the high-quality development and global competitiveness of cities. The spatial distribution characteristics and influencing factors of innovation are of significant value in optimizing the allocation of innovation resources. This study focuses on Harbin, utilizing 46,057 patent application data from 2004 to 2022, and employs spatial analysis methods such as KDE, ESDA, and DBSCAN to analyze the spatiotemporal evolution patterns of innovation space. Through the MGWR model, this study investigates the factors influencing the spatial agglomeration of innovation from five dimensions: innovation subjects, infrastructure support, public service support, population and market, and spatial carrier. The findings are as follows: (1) In terms of spatiotemporal patterns, Harbin's innovation space distribution shows a "one core, four cluster" spatial structure, with innovation activities clustering primarily around universities as the core and new districts as key support, gradually evolving toward a multi-center agglomeration development model. (2) Regarding influencing factors, the geographic proximity of universities is significantly associated with higher innovation density. Among infrastructure, metro stations show a positive association with innovation agglomeration, potentially reflecting the role of transport accessibility. Public service support displays significant spatial heterogeneity across different regions. (3) The Historical Area requires policy guidance for urban renewal; the New Town Area forms exogenous-driven innovation clusters; the Industrialized Park Area achieves endogenous development through industrial collaboration.

Keywords: innovation space; innovation activities; spatiotemporal evolution characteristics; influencing factors; Harbin

1. Introduction

As the global economy enters the era of innovation-driven development, knowledge economy and technological innovation have become core drivers for cities to compete globally. Urban innovation space, as the carrier of innovation activities and the agglomeration of innovation factors, shapes whether spatial structures support high-quality socio-economic development through innovation. Its distribution patterns result from interactions of socio-economic and cultural forces [1], influenced by objective and subjective factors, warranting comprehensive spatiotemporal analysis to guide policy and enhance vitality [2]. The distribution of innovation activities in space is agglomerated and uneven, with high

concentration in a few narrow geographic areas of a country, such as Silicon Valley in the United States, which serves as a model for highly concentrated technological innovation in developed countries and even globally [3]. Its technological innovation is mainly concentrated in a narrow "triangular" geographic space [4]. This agglomeration model generates substantial advantages including knowledge spillovers, specialized labor markets, and robust innovation ecosystems that facilitate face-to-face interaction and resource sharing. However, it also presents significant drawbacks, particularly escalating costs (housing, land, labor), exacerbated regional inequality through brain drain from peripheral areas, and increased systemic vulnerabilities to external shocks. In recent years, innovation agglomeration has been shown to directly influence a country or region's innovation capacity and competitiveness, yet measuring and describing this phenomenon remain challenging [5,6]. The level of innovation agglomeration restricts economic productivity [7], and the formation mechanisms of innovation cooperation, among others, need to be distinguished and identified [4]. The big data era and interdisciplinary approaches now enable quantitative studies of innovation clustering, revealing deeper intercity connections and spatial organization.

The spatial agglomeration of innovation activities is central to innovation space research. Globally and regionally, innovation concentrates in a few areas [8,9]. Scholars quantify agglomeration using R&D investment, patent counts, and new-product outputs, measured with indices like the Herfindahl Index, Gini Coefficient [10], and EG Index [11], while continuous spatial analysis methods refine these measures [4]. Additionally, in studies on spatial scale, some scholars found that innovation clustering is highly distance-sensitive, with efficient clusters forming only within very small spatial ranges [12]: patent citations decline sharply with distance [13], and knowledge spillovers within 1 km exceed those at 2–5 km by over tenfold and virtually vanish beyond 10 km [14]. However, geographic proximity alone is neither sufficient nor necessary; organizational, institutional, technological, and social proximities also matter, leading to the multidimensional proximity concept [15].

Explaining spatial clustering involves three core mechanisms: knowledge spillover, matching, and sharing [16]. Knowledge spillover—the transmission of uncertain, tacit knowledge—relies on face-to-face interaction to reduce transaction costs like negotiation and technical guidance [5,17–19]. Knowledge externalities within industrial clusters further enhance innovation output [20,21]. The matching mechanism improves high-skilled labor markets by increasing mobility and accelerating knowledge diffusion [22–24]. The sharing mechanism, via scale returns, fosters specialization in innovation services, lowering costs and encouraging innovation [25,26].

Empirical urban studies have applied these insights. Duan Jie and Meng Guoli examined policy-driven carriers, revealing spatial patterns and driving logic of platforms like industrial parks and makerspaces [27,28]; Luan Feng used micro-location theory to demonstrate significant clustering within a 500 m radius of high-level public service nodes, metro hubs, and universities [29]. Against the backdrop of innovations in data science methods, scholars such as Duan Dezhong and Li Lingyue visualized urban innovation spaces using big data on patents, publications, and other outputs [2,30]. Wang Jiwu developed predictive models to forecast trends in innovation space evolution [31].

The evaluation of urban innovation activities and their drivers has been approached from multiple angles. Esmaeilpoorarabi et al. combined qualitative and quantitative methods to analyze four cities [32] and three innovation districts in one city [33], identifying five innovation-cluster dimensions—context, form, function, ambiance, and image. They argued that effective innovation environments balance "hard" factors (economy, infrastructure) with "soft" factors (culture, society). Using two Delphi rounds and AHP,

they developed the Delphic Hierarchy Process (DHP) to weight indicators and build a multi-level evaluation framework spanning regional, city, and cluster scales [34].

Other scholars have developed systems for identifying the influencing factors of urban innovation space distribution and clustering, focusing on the determination of influencing factors, research data, and methods. Li Lingyue, analyzing Shanghai patent data (2000–2015), documented micro-scale clustering evolving into a multi-center network. They found enterprises dominant, with universities and individuals also contributing, and showed that public budget expenditure and green-space area significantly boost overall innovation output [2]. Wang Jiwu applied a Boosting ensemble algorithm in Hangzhou to decompose seven factors—industry concentration, knowledge intensity, talent resources, service facilities, external and public transport convenience, and ecological environment—within an explanatory framework [31]. Yang Chengfeng used OLS and spatial econometric models on Hefei POI data to classify influencers into market potential, clustering environment, and surrounding built environment [35]. Guan Manling proposed a generalized urban innovation space framework for Nanjing's core area and conducted a layered, multi-scale geographically weighted regression analysis of three innovation space types [36].

The above studies have established spatial correlations between innovation activities and patent outputs at regional and urban scales, enriching understanding of clustering and its determinants. However, there are still gaps in existing research. First, most studies target macro- [37–39] and medium-scale urban areas [31,40], leaving micro-scale, multi-type innovation patterns within cities underexplored. Second, although cities concentrate talent, technology, capital, and enterprises [41–43], existing work predominantly examines broader regional trends and intra-urban comparisons rather than detailed spatial layouts of diverse innovation subjects [30,44]. Moreover, the emphasis on innovative enterprises overlooks other actors and actual innovation outputs, creating a gap in quantitative, medium- and micro-scale analyses from an output perspective.

To summarize the development patterns of innovation activities across time and space, identify potential growth areas, elucidate the generation and development mechanisms of innovation spaces, and provide references for the future development of urban innovation spaces, this study builds a GIS database of Harbin patent data and employs multidimensional spatial analysis models to investigate two core questions. First, it reveals the spatial distribution characteristics and spatiotemporal evolutionary patterns of innovation activities through agglomeration analysis. Second, it establishes a systematic framework to identify the determinants and mechanisms of innovation space formation.

By addressing these research gaps, this study advances existing knowledge in three dimensions. Theoretically, it enriches micro-scale and multi-type innovation activity research while promoting multidisciplinary integration across management, economics, geography, and urban planning. Methodologically, it develops quantitative analytical approaches that integrate multi-source big data for micro-scale innovation space analysis. Practically, it provides empirical evidence for planners to optimize innovation resource allocation and formulate differentiated policies, ultimately guiding efforts to boost Harbin's innovation vitality and foster high-quality urban socio-economic growth.

2. Materials and Methods

This section provides an integrated description of the study area, the research data employed, and the methodology adopted in this research. A concise summary of the analytical steps is illustrated in the accompanying flowchart (Figure 1) to offer a clear and systematic overview of the research design.

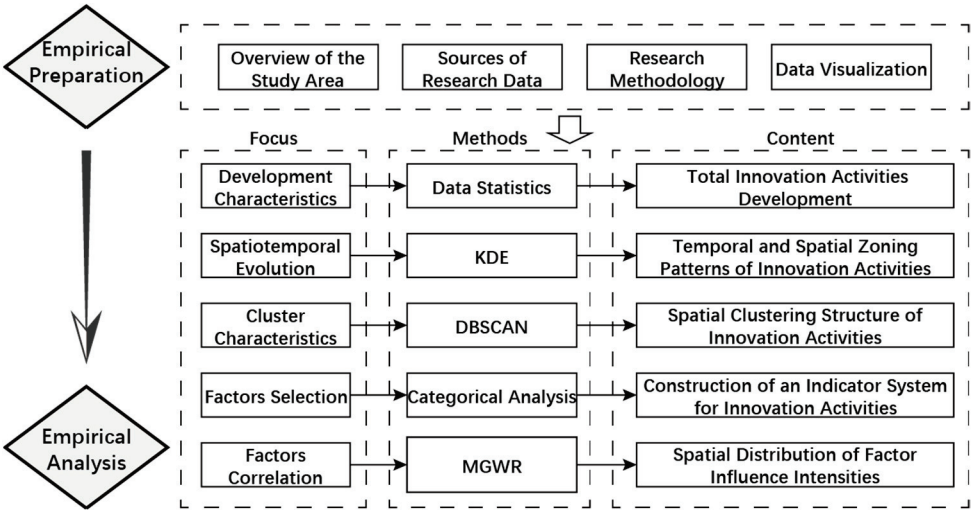

Figure 1. Flowchart of the methodological framework.

2.1. Overview of the Study Area

The study combines the distribution characteristics of patent data and delineates the study area as the central urban area of the Territorial Spatial Master Plan of Harbin Municipality (2021–2035), encompassing the Nangang, Xiangfang, Daoli, Daowai, Pingfang, Songbei, and Hulan Districts [45,46]. Harbin, a core city in China's northern opening-up and leader of the Harbin–Daqing–Qiqihar National Independent Innovation Demonstration Zone [47,48], is pivotal to revitalizing the Northeast's industrial base and driving regional innovation. In 2022, Harbin's GDP reached CNY 549.01 billion. Calculated at comparable prices, this figure represents a 2.5% increase compared with the previous year. In terms of industrial structure, the city has established a "tertiary–secondary–primary" development pattern dominated by the tertiary sector. Regarding population composition, by the end of 2022, Harbin had a registered population of 9.395 million, including 5.286 million registered urban residents, corresponding to a registered urbanization rate of 56.3%.

2.2. Research Data

Quantitative research on urban innovation spaces commonly uses STI (Science, Technology, Innovation) data—including innovation inputs, outputs, media, and networks—to capture different aspects of innovation. Among these, output data, particularly inventions and patent applications, is vital for mapping spatial distribution and temporal trends [8] and has become the primary metric in spatial innovation studies [9–11]. Patent applications, as key output indicators, reflect the type and status of innovation activities and underpin analyses of innovation volume, spatial clustering, disciplinary patterns, and evolution. Patent records capture both intermediate outputs and final market products, bridging R&D efforts and commercial outcomes. These data record applicant categories, addresses, application years, and subject classifications, effectively delineating spatial and sectoral characteristics of urban innovation.

Due to the limited availability of patent records in Harbin before 2000, this study focuses on the period from 2004 to 2022. A total of 48,172 patent applications were retrieved from the PatSnap database, and after removing duplicates, invalid or expired patents, incomplete records, and entries outside the study area, 46,057 valid patents were retained. It is important to clarify that, in the analysis of influencing factors, the dependent variable reflects the stock of patents that remained valid as of 2022, rather than the cumulative filing volume from 2004 to 2022. Therefore, the variable reflects the state of innovation outcomes in 2022, which aligns temporally with the built environment and socio-economic indicators

(primarily drawn from 2020–2022 datasets), avoiding a temporal mismatch between the dependent and independent variables.

All valid patent records, including applicant type, address, filing year, and technological category, were geocoded in ArcGIS Pro 3.1 to construct the spatial dataset used in the analysis (Figure 2). A meso-to-micro analytical framework was then applied to assess the multidimensional spatial distribution of innovation using spatial econometric modeling techniques.

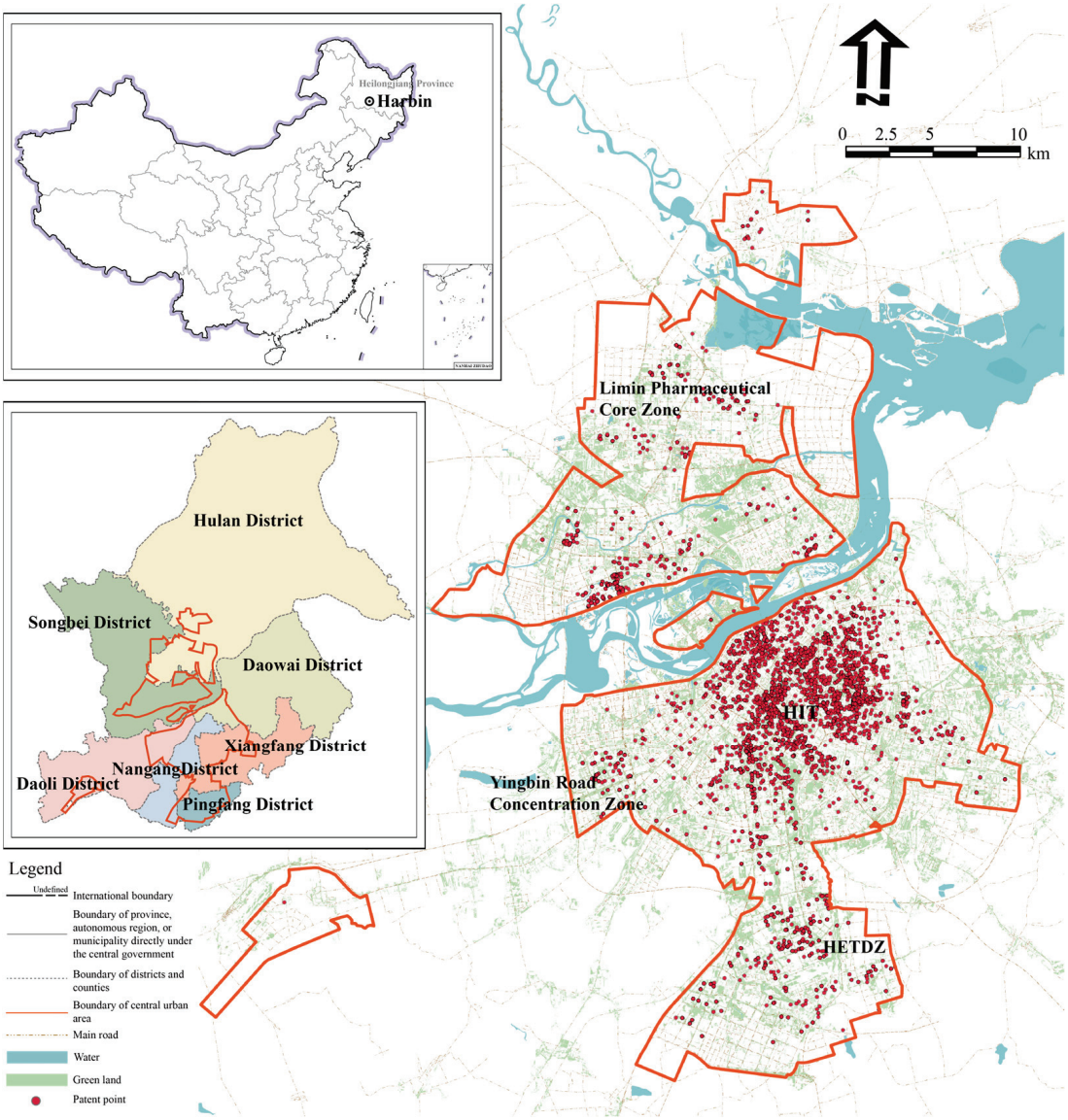

Figure 2. Location of the studied area and spatial distribution of patent data.

While this approach ensures temporal consistency between variables, it should be noted that the validity year of patents does not fully capture their temporal filing sequence. Due to the lack of complete historical data for explanatory variables, this study is unable to distinguish the temporal lag effects between patent generation and changes in the built environment. This limitation is acknowledged, and future research may incorporate yearly patent records and historical POI or demographic data to construct longitudinal or panel-based models, enabling more explicit analysis of temporal dynamics.

Based on the research framework of integrating meso and micro scales, this study uses spatial econometric models to analyze the multidimensional distribution patterns

of urban innovation spaces. The research area is divided into a 1 km × 1 km regular grid, consisting of 878 grid units, which serve as the basic units for innovation space analysis. During the regression analysis, Harbin's patent application data are selected as indicators representing the distribution of innovation space. By spatially discretizing the data, the number of innovation spaces is overlaid on the grid system, generating 878 valid observations for the innovation space study unit. Compared to macro-level statistics of innovation space quantity, the spatial density index based on grid units better reveals the spatial heterogeneity of innovation factors at the micro scale.

2.3. Indicator System

Based on existing relevant research, this study integrates macro-level factors with micro-level service facility data to establish an influencing factor index system across five dimensions: innovation subjects, infrastructure, public services, population and market, and spatial carriers (Figure 3). Studies with different research objects are used to inform the selection of analytical dimensions and the quantitative methods for variable measurement, while studies with similar research objects are used to identify appropriate influencing factors. By integrating both sources of reference, a refined and context-specific index system of influencing factors is established.

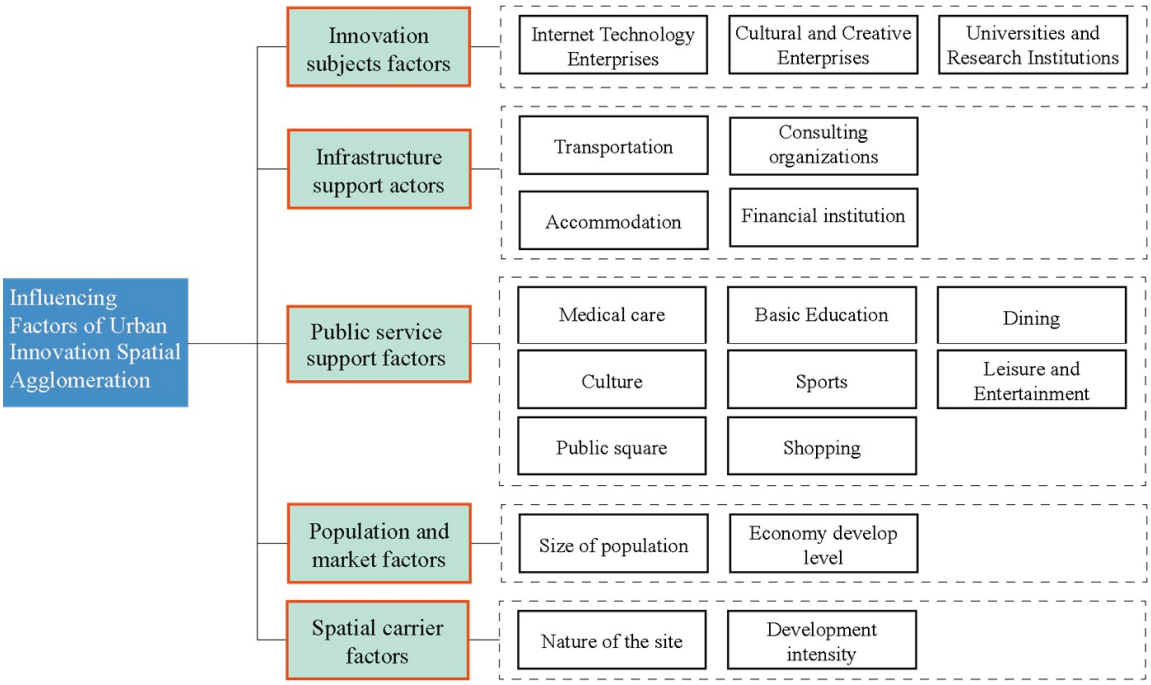

Figure 3. System of factors influencing innovation space.

Studies on factors affecting the distribution of different types of spaces, such as the research on hackerspaces in Nanjing, propose a four-dimensional framework—policy, transportation, market, and innovation—with eleven specific indicators [49]. Research on hackerspaces in Fuzhou and Shenzhen identifies five dimensions—innovation atmosphere, living services, policy environment, inclusiveness, and traffic—and 23 detailed indicators [50]; similarly, a study on new-generation information technology enterprises in Nanjing develops an eight-first-level dimensional system that includes land cost, industrial base, labor resources, policy foundation, production services, ecological services, public services, and living services—further subdivided into second-level dimensions and indicators for a comprehensive multidimensional evaluation [51].

In the research on factors influencing innovation spaces, studies on Shenzhen's innovation space indicator system include variables such as the number of universities/research institutions, manufacturing enterprises, information technology enterprises, and cultural innovation enterprises, and the number of metro stations, bus stops, hospitals, dining facilities, sports facilities, and leisure facilities [52]. Research on the innovation space pattern in Nanjing categorizes factors into innovation environment support—ecological, industrial, investment, and policy—and innovation entity services—transportation, dining, shopping, cultural, leisure, and production services [36].

Drawing from these studies and considering data availability, this research selects 27 influencing factors to form a three-level indicator system (Table 1). Data sources comprise POI from Gao De Map and China Eyeballs (Chinese company search engine), population statistics from WorldPop, and land use data from the Status Map of the Territorial Spatial Master Plan of Harbin Municipality (2021–2035). Through Variance Inflation Factor (VIF) testing, the medical facility density variable exhibits VIF > 7.5 and is therefore excluded to reduce covariance interference in subsequent regression analyses.

Table 1. Factors influencing innovation space clustering and data sources.

First Dimension	Secondary Dimensions	Explanation of Influencing Factors	Unit of Measure	Source of Data
Innovative subject factors	Internet technology enterprises	Density of internet technology enterprises in the grid	pcs/km^2	Harbin POI data for 2022
	Cultural and creative enterprises	Density of cultural and creative enterprises in the grid	pcs/km^2	
	Distance between nearest universities/research institutes and center point	Distance between nearest universities/research institutes and center point	m	
Infrastructure support factors	Transport facilities	Density of public transport stops in the grid	pcs/km^2	Harbin POI data for 2022
		Distance between nearest metro stations and center point	m	
		Distance between nearest major transportation hub and center point	m	
		Area of overlap between grid and road buffer zone	m^2/km^2	
		Density of parking facilities in the grid	pcs/km^2	
	Innovation support facilities	Distance from the center of the grid to the nearest advisory body (law, accounting, patent, auditing, etc.)	m	
		Density of financial institutions in the grid (financial and insurance institutions, banks, etc.)	pcs/km^2	
		Density of accommodation facilities in the grid	pcs/km^2	
Public service support factors	Medical facility	Distance from the center of the grid to the nearest medical facility	m	Harbin POI data for 2022
	Elementary education	Distance from the center of the grid to the nearest primary or secondary school	m	
	Dining and shopping facilities	Density of catering outlets in the grid	pcs/km^2	
		Density of convenience stores in the grid	pcs/km^2	
		Distance between nearest shopping centers and center point	m	
	Sports and leisure facilities	Density of sports facilities in the grid	pcs/km^2	
		Density of cinemas, theaters, bars, and KTVs in the grid	pcs/km^2	
		Density of libraries, bookshops, museums, exhibition halls, and galleries in the grid	pcs/km^2	
		Distance between nearest park square and center point	m	
Population and market factors	Size of population	Density of population in the grid	Hundred persons/km^2	Worldpop website Harbin 2020 population data
Spatial carrier factors	Nature of site	Land use mix ratio in the grid	/	Territorial Spatial Master Plan of Harbin Municipality (2021–2035) Status Map
		Percentage of residential land in the grid	%	
		Percentage of administration land in the grid	%	
		Percentage of business land in the grid	%	
		Percentage of manufacture land in the grid	%	
		Percentage of utilities land in the grid	%	

2.4. Research Methodology

This study adopts three principal analytical methods—kernel density estimation (KDE), Density-Based Spatial Clustering of Applications with Noise (DBSCAN), and multiscale geographically weighted regression (MGWR)—to examine the spatiotemporal distribution patterns and potential influencing mechanisms of patent applications in Harbin. The selection and ordering of these methods correspond to the overarching analytical framework of the research: (1) KDE is applied to characterize the spatial evolution and temporal dynamics of innovation activities. The results reveal overarching spatial dynamics and provide a foundational reference for identifying areas of concentration in subsequent analyses. (2) DBSCAN is employed to identify clustering trends, cluster structures, and potential innovation hotspots. The clustering outputs refine the understanding of spatial configuration and support the recognition of innovation spatial structures. (3) MGWR is utilized to explore spatially varying relationships between patent activity and a set of explanatory factors, thereby providing a tentative interpretation of possible localized drivers underlying spatial heterogeneity. The results provide exploratory evidence that helps interpret variations in spatial patterns observed in KDE and DBSCAN. In addition to these core analytical approaches, supplementary methods are incorporated where appropriate. The complete methodological procedures are presented below.

2.4.1. Kernel Density Analysis

KDE, as a distance-decay-based smoothing estimation, is suitable for capturing continuous spatial intensity patterns without requiring predefined boundaries. The model is as follows:

$$\hat{f}(x) = \frac{1}{nh}\sum_{i=1}^{n} K(\frac{x - x_i}{h}) \tag{1}$$

where x_1, x_2. . .x_n are independently distributed n patent application data; h denotes the bandwidth; the kernel K is a symmetric function that integrates to one and determines the local weighting (distance decay) around x; and the estimator $\hat{f}(x)$ is an estimated density (intensity) at x.

2.4.2. DBSCAN Clustering Algorithm

DBSCAN is appropriate for detecting irregular spatial clusters and distinguishing meaningful innovation agglomerations from dispersed noise. The DBSCAN algorithm is capable of dividing sufficiently dense regions into clusters, and can effectively deal with noise points to discover spatial clusters of arbitrary shape. The algorithm mainly contains 2 important parameters: *Eps* and *MinPts*. *Eps* refers to the neighborhood distance; *MinPts* refers to the minimum number of samples contained in the neighborhood of *Eps* [53]. In this study, the algorithm is used to identify the spatial aggregation characteristics of patent data in Harbin, and the optimal parameters are selected with the help of a *k-dist* plot after several iterations in order to obtain the optimal clustering results.

2.4.3. Measurement of Land Use Mix Ratio

Referring to the calculation method of the degree of land use mix in existing studies [54], the specific calculation formula is as follows:

$$Landusemix_i = \frac{-\sum_{i=1}^{k} P_{ki} ln(P_{ki})}{lnk} \tag{2}$$

The constraints are

$$\sum_{k=1}^{6} P_{ki} = 1 \tag{3}$$

where $Landusemix_i$ is the entropy value indicating the degree of land use mix; k is the number of land use types in grid i. In this paper, according to the current status map of land use status and land use type classification of the Territorial Spatial Master Plan of Harbin Municipality (2021–2035), six land use types related to innovation space were selected—residential land, administration land, business land, industrial land, manufacture land, and utilities land—with other types classified into one category, and thus, k = 6; P_{ki} denotes the proportion of the k-th land use type in the total area of grid i. The value of $Landusemix_i$ obtained according to Equation (2) ranges from 0 to 1, where a higher value indicates a more balanced distribution of land uses, i.e., a higher degree of land use mix, while a lower value indicates a less balanced distribution.

2.4.4. Ordinary Least Squares Method

To study the impact of different factors on the distribution of innovation space, this study first performs spatial regression analysis using the Ordinary Least Squares (OLS) method, one of the most commonly used regression methods. The equation is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon \quad (4)$$

where Y is the dependent variable; β_0 is the equation constant; β_n is the coefficient of the independent variable X_n; and ε is the random error.

2.4.5. Multi-Scale Geographically Weighted Regression Analysis

Innovation space aggregation is often the result of multiple influencing factors acting together, requiring a comprehensive consideration of the influence scale of each independent variable. To avoid analysis errors caused by the equalization of influence scales, this study adopts the MGWR model to explore the relationship between independent and dependent variables, comparing the model's fit with the OLS model and the classic geographically weighted regression (GWR) model to select the optimal model.

$$Y_i = \beta_0(u_i, v_i) + \sum_{k=1}^{p} \beta_{bwk}(u_i, v_i) x_{ik} + \varepsilon_i \quad (5)$$

where (u_i,v_i) is the center geographic coordinate of the i-th sample; β_k(u_i,v_i) is the value of the continuous function β_k(u,v) in the i-th sample's spatial unit; bwk is the bandwidth used for the regression coefficients of the k-th variable; and β_{bwk} is the locally estimated regression coefficient, with specific bandwidth for each variable.

3. Results

3.1. Characterization of the Spatial Evolution Pattern of Innovation Activities

3.1.1. Analysis Framework of Innovation Activities

Through statistical analysis, kernel density estimation, and clustering analysis, this study investigates the overall characteristics of innovation activities in Harbin and their multi-scale spatiotemporal evolution (Figure 4). First, the general characteristics of innovation activities are examined to identify their temporal patterns, actor attributes, and technological theme structures. Subsequently, the spatial dimension of innovation activities is explored by analyzing temporal dynamics and regional patterns to reveal the evolutionary characteristics of innovation space. Finally, the analysis focuses on the spatial agglomeration of innovation, clarifying the developmental trajectory and underlying mechanisms of innovation clustering.

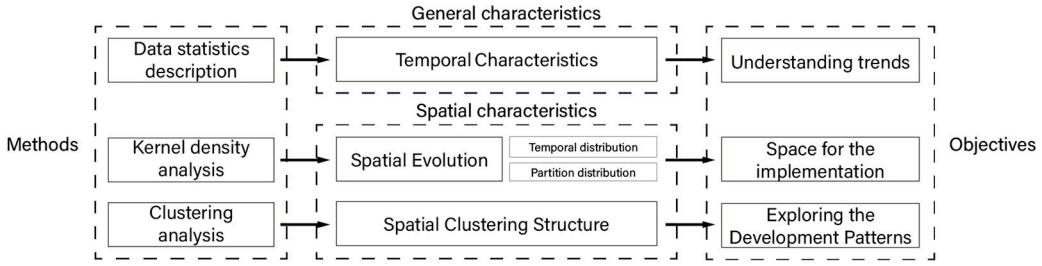

Figure 4. Flowchart of the research on the spatial evolution pattern of innovation activities.

3.1.2. Temporal Evolution of Innovation Activities

From a temporal perspective, annual patent applications in Harbin (2004–2022) (Figure 5) exhibit four phases: slow rise, rapid surge, slight fluctuation, and sharp short-term decline. From 407 applications in 2004 to 1802 in 2011, applications grew at an average of 199.3 per year. Between 2011 and 2015, annual growth accelerated to 775.2 applications, peaking at 4360 in 2019. By 2022, patent applications declined sharply. While COVID-19 disruptions—including reduced onsite R&D activity in universities and industrial parks—likely contributed to this downturn, recent changes in China's national patent policy framework (such as stricter examination standards, the shift from quantity-driven to quality-oriented evaluation, and the removal of patent subsidies) may also have played an important role. Therefore, the decrease may reflect both temporary pandemic effects and long-term institutional adjustments in the patent system [55].

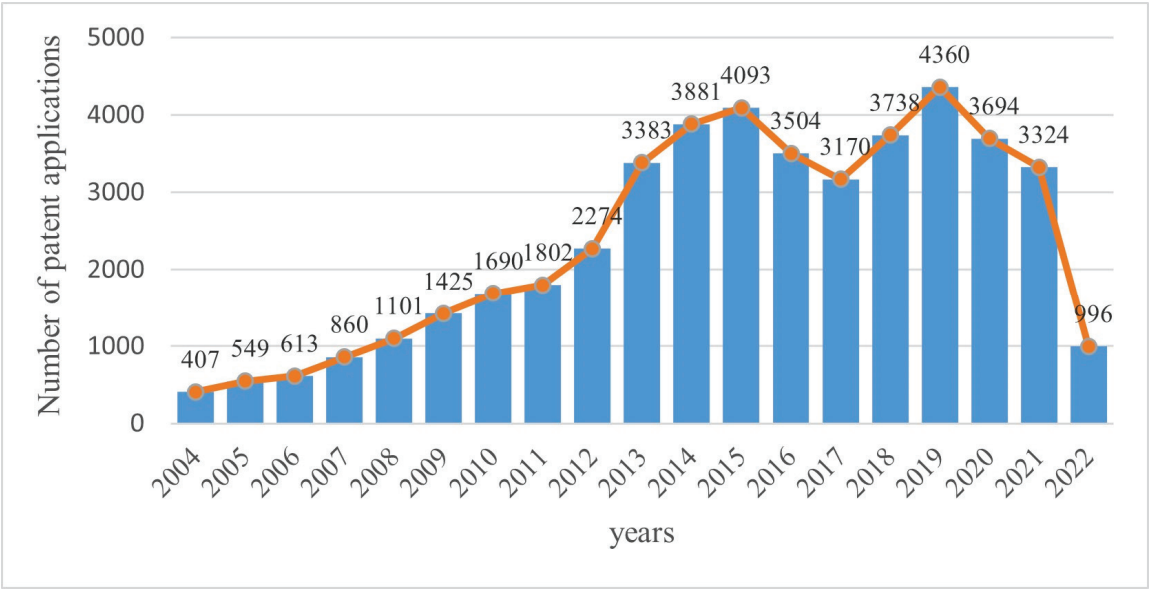

Figure 5. Statistical chart of the number of patent applications filed in Harbin year by year.

3.1.3. Spatial Evolution of Innovation Activities

① Temporal Distribution of Innovation Activities

Kernel density analysis for 2004, 2010, and 2022 (Figure 4) maps the spatiotemporal dynamics of innovation in Harbin's central urban districts. In 2004, innovation was nascent and concentrated around major universities, with minimal activity in the Harbin Economic and Technological Development Zone (HETDZ) and scattered instances in Songbei District (Figure 6a). By 2010, HETDZ and Songbei's activity had grown, yielding a "one core, two wings" pattern: a central core around Nangang's universities supported by the HETDZ and Songbei, alongside emerging eastern clusters (Figure 6b). In 2022, innovation space

expanded rapidly into a "one core, four clusters" structure (Figure 6c). The historical core—centered on Harbin Institute of Technology (HIT), Harbin Engineering University (HEU), and environs—formed a high-density nucleus. Four peripheral clusters emerged: the Li-min Pharmaceutical Core Zone in Hulan District, Songbei Science and Technology Innovation City, Yingbin Road Concentration Zone, and HETDZ. This configuration underscores key universities' centrality in innovation and industrial parks' role in integrating external resources.

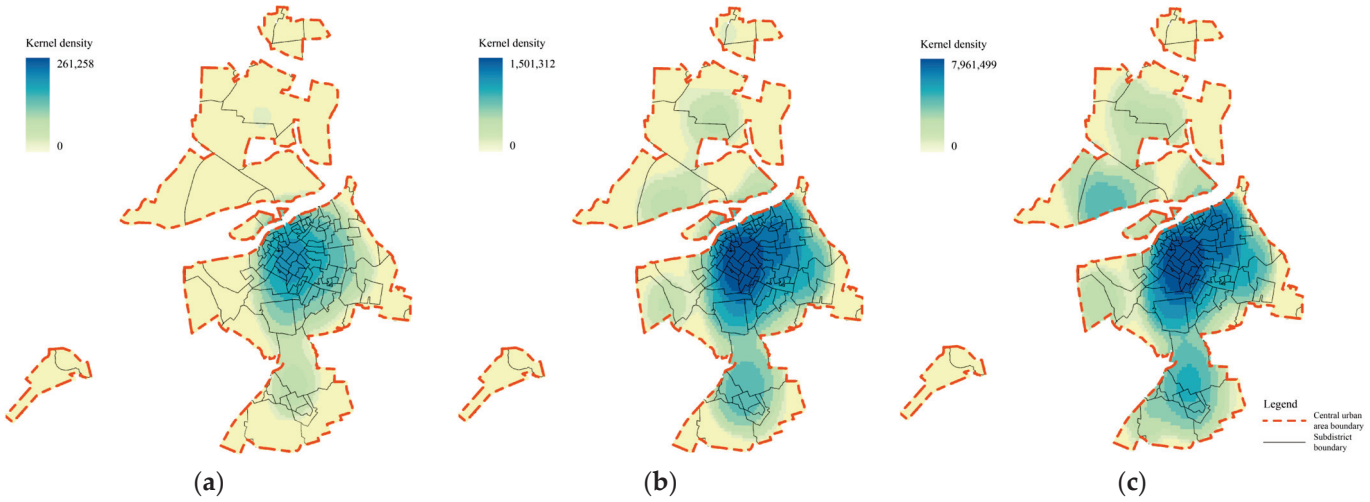

Figure 6. Spatial kernel density of innovation activities analyzed over time: (**a**) 2004; (**b**) 2010; (**c**) 2022.

② Innovation Activity Partition Distribution

The KDE results of the current innovation activities were reclassified by a standard deviation-based approach. Specifically, the continuous density surface was categorized according to ±1 standard deviation from the mean density. The standard deviation classification emphasizes deviations from the mean density, ensuring that cluster cores are visually distinguishable from surrounding lower-density areas. This method highlights the core structure of innovation clusters, allowing for clear identification of high-density aggregation areas.

As a result (Figure 7a), one major high-density core and two smaller dispersed cores were identified. Accordingly, Harbin's central urban innovation space was partitioned into three components, refined by spatial evolution, industrial concentration, and administrative hierarchy: the Historical Area primarily includes parts of Nangang District, Xiangfang District, Daoli District, and Daowai District; the Industrialized Park Area mainly includes the HETDZ in Xiangfang District and Pingfang District, and parts of Haxi New District in Nangang District and Daoli District; and the New Town Area includes parts of Songbei District and Hulan District (Figure 7b).

Kernel density analysis was conducted on patent data for the three areas, mapped to subdistrict-level city maps to assess innovation space distribution. Historical Area: Innovation space centers on HIT, with HEU forming a secondary core, together creating a saddle-like pattern (Figure 8a). These universities, along with Northeast Agricultural University, Northeast Forestry University, and Harbin University of Science and Technology, exert a radiation effect across the area, forming a major innovation hub in Harbin's central urban region.

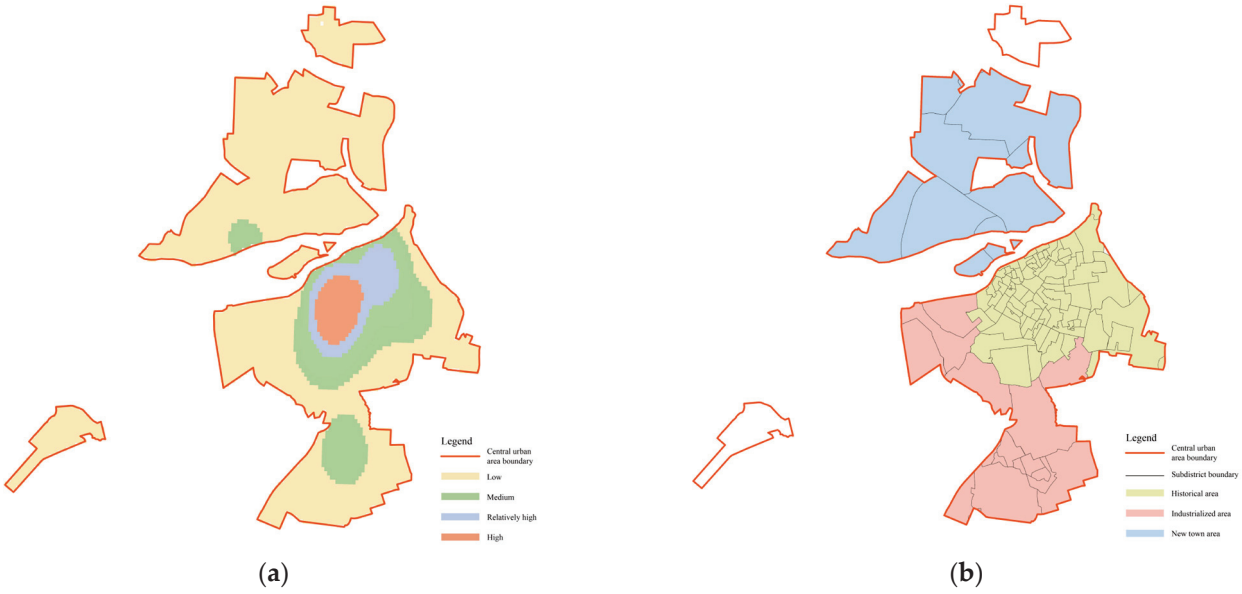

Figure 7. Innovation activity partition distribution: (**a**) standard deviation classification of kernel density; (**b**) zoning map of innovation activity space.

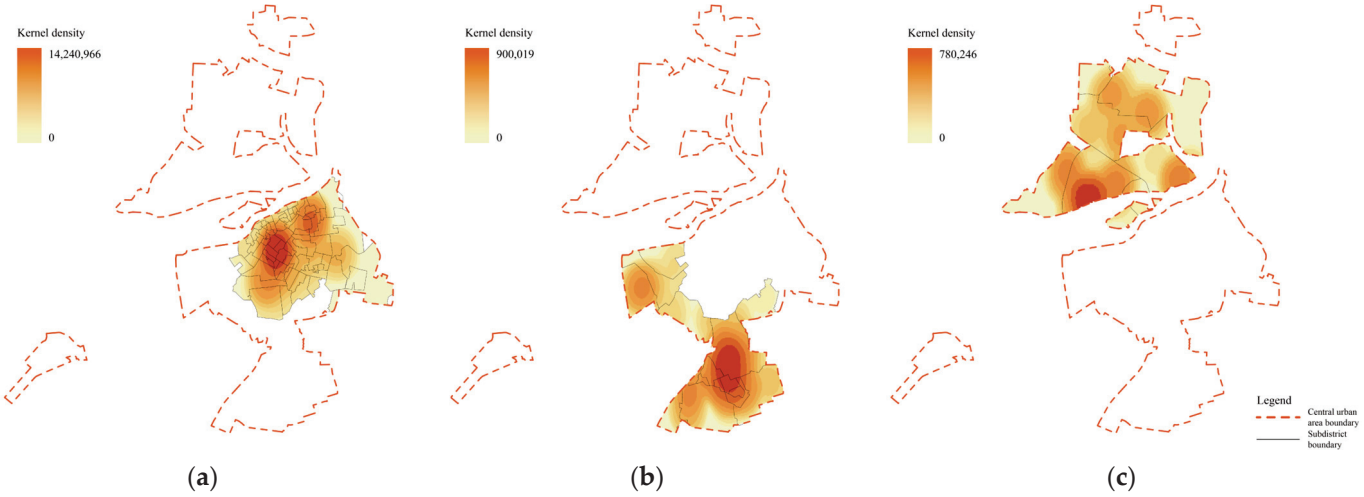

Figure 8. Kernel density analysis of spatial zoning for innovation activities: (**a**) Historical Area; (**b**) Industrialized Park Area; (**c**) New Town Area.

Industrialized Park Area: Innovation activities concentrate in the HETDZ of the Xiangfang and Pingfang Districts, with secondary activity in the Harbin High-Tech Industrial Development Zone and Yingbin Road Concentration Zone, forming a "main–secondary" structure (Figure 8b). Due to geographical distance and limited interaction, these areas are evolving into separate innovation poles in the south and west.

New Town Area: This area's innovation space includes the Songbei Digital Economy Industrial Park, Shenzhen–Harbin Biotechnology Industrial Incubation Park, and Li-min Pharmaceutical Core Zone in Hulan District (Figure 8c). These small, dispersed parks form a multi-point, multi-core pattern. While individual cores are weak in radiation and scattered, they show increasing influence and signs of interconnection.

3.1.4. Spatial Clustering Analysis Based on DBSCAN

Using the k-dist graph and iterative testing, optimal DBSCAN parameters were set as MinPts = 4 and Eps = 300 m (Figure 9), producing 228 clearly bounded clusters (Figure 9). Most clusters concentrate in the Historical Area, especially near universities and research

institutes, often aligning with administrative boundaries. The largest cluster (cluster 1) spans the northern Nangang and western Xiangfang Districts; the second-largest (cluster 2) lies in the eastern Daoli and western Daowai Districts. Outside the Historical Area, clusters are fewer, smaller, and loosely packed, reflecting weaker innovation agglomeration consistent with the broader innovation space pattern.

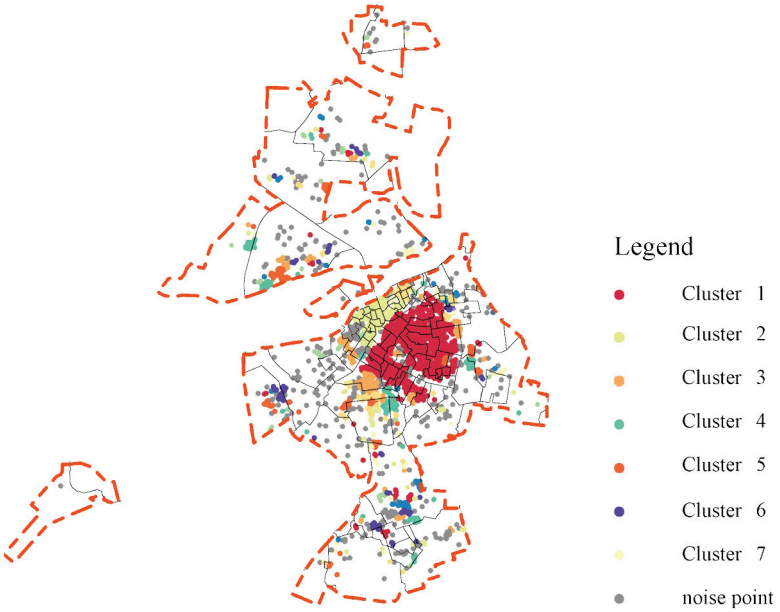

Figure 9. Distribution of spatial clusters of innovation activities identified by DBSCAN.

3.2. Analysis of Influencing Factors

3.2.1. Regression Model Selection and Comparison

The OLS model, GWR model, and MGWR model were constructed, and after comprehensive consideration of residual sum of squares, AICc, −2 log-likelihood, and adjusted R^2, the MGWR model showed the best performance (Table 2). Therefore, the MGWR model was selected for further analysis.

Table 2. OLS, GWR, and MGWR model fitting effects.

Modeling	Residual Sum of Squares	−2 log-Likelihood	AICc	R Square
OLS model	2196.6291	−1648.4054	3337.7909	0.4048
GWR model	403.605	−904.633	2239.974	0.540
MGWR model	350.326	−842.483	2046.176	0.601

3.2.2. Intensity of Effect of Influencing Factors

The coefficients from the MGWR analysis of innovation space were summarized, and the results are shown in Table 3.

Table 3. Statistics on the results of the overall MGWR coefficient for innovation spaces.

Variant	Average Value	Minimum Value	Maximum Value	Significant Coefficient Proportion
Density of internet technology enterprises	1.743	−4.296	19.148	42.597%
Density of cultural and creative enterprises	−0.068	−0.091	−0.007	0.000%
Distance to universities/research institutes	−0.181	−1.043	1.820	34.624%

Table 3. *Cont.*

Variant	Average Value	Minimum Value	Maximum Value	Significant Coefficient Proportion
Density of bus stops	0.046	0.042	0.055	0.000%
Distance to metro stations and center point	−0.462	−3.343	1.159	47.722%
Distance to nearest major transportation hub	0.063	0.055	0.074	0.000%
Road buffer zone area	0.069	0.056	0.084	76.424%
Density of parking facility	−0.005	−0.008	0.001	0.000%
Distance to advisory bodies	−0.712	−2.830	1.017	55.923%
Density of financial facilities	−0.043	−0.048	−0.034	0.000%
Density of accommodation facilities	0.028	−0.116	0.531	12.984%
Distance to primary/secondary schools	−0.038	−0.049	−0.030	0.000%
Density of dining facilities	−0.269	−0.271	−0.265	100.000%
Density of convenient stores	−0.001	−0.003	0.006	0.000%
Distance to nearest shopping centers	−0.172	−1.657	0.714	37.472%
Density of sports facilities	0.228	0.086	0.275	94.413%
Density of leisure facilities	−0.036	−0.092	0.138	0.000%
Density of cultural facilities	0.119	−3.169	4.573	59.681%
Distance to park square	−0.112	−1.519	1.007	37.699%
Density of population	−0.086	−0.089	−0.085	93.964%
Land use mix ratio	0.005	−0.009	0.008	0.000%
Percentage of residential land	0.025	−0.261	0.278	23.576%
Percentage of administration land	0.102	−1.189	1.109	17.995%
Percentage of business land	−0.002	−0.019	0.014	0.000%
Percentage of manufacture land	0.036	−0.014	0.078	0.000%
Percentage of utilities land	0.011	−0.002	0.022	0.000%

① Significant coefficient proportion

The significant coefficient proportion refers to the share of grid units where explanatory variables are statistically significant ($p < 0.05$), indicating the spatial robustness of variable effects.

Based on the results, variables like Road buffer zone area, Density of dining facilities, and Density of sports facilities show significant coefficients in over 75% of grid units, suggesting strong influence on innovation activities. Variables like Distance between nearest advisory bodies and center point and Density of cultural facilities (50–75%) show moderate spatial correlations. Variables such as Internet technology enterprises, Distance between nearest universities/research institutes and center point, and Distance between nearest metro stations and center point have less than 50%, showing weaker spatial explanatory power. Some variables with 0% significance (e.g., Density of leisure facilities) had no notable local impact. Notably, results from global and local models may diverge; for instance, Density of dining facilities is globally insignificant but has 100% local significance, likely due to spatial heterogeneity masking global effects.

② Extreme value of coefficients

Extreme value analysis examines variable behavior in different regions. Variables such as Internet technology enterprises, Distance between nearest universities/research institutes and center point, and Density of cultural facilities had large fluctuations, indicating varying regional effects. Variables like Density of sports facilities, Distance between nearest major transportation hub and center point, and Road buffer zone area exhibited smaller variations, suggesting more stable performance. Many variables showed both positive and negative effects depending on location, underscoring the need to further explore spatial boundaries where factor effects shift.

③ Average value of coefficients

Average value analysis captures the overall direction and dominant magnitude of each factor's influence across the study area. In this study, most density- and land use-related variables (such as densities of service facilities and the road buffer zone area) present small-to-moderate positive mean coefficients, indicating that, on average, higher levels of these resources are associated with higher innovation intensity. By contrast, distance-based variables (for example, distances to metro stations, universities or research institutes, and major commercial centers) tend to exhibit negative mean coefficients, consistent with the expectation that closer proximity to key transport and knowledge hubs generally promotes innovation clustering. The fact that many mean values remain close to zero nevertheless suggests that no single factor exerts a uniformly strong effect citywide, reinforcing the view that the formation of innovation space is shaped by locally contingent combinations of multiple drivers rather than by any single dominant determinant.

3.2.3. Spatial Distribution of Influencing Factors

Based on the results of the MGWR model, the absolute value of regression coefficients was used to measure the strength of factor effects, and the significant coefficient proportion was used to characterize their relative contribution rate. Combining these initial analyses, significant variables with a non-zero significant coefficient proportion and $p < 0.05$ in the grid units were selected for spatial distribution analysis (Figure 10). According to the previous classification of influencing factors (Table 1), the significant variables were divided into five categories: innovation subject factors, infrastructure support factors, public service support factors, population and market factors, and spatial carrier factors. These categories were then used to construct an analysis system to reveal the spatial differentiation patterns of their impact strength.

① Innovation Subject Factors

The Internet technology enterprise variable exhibits high spatial heterogeneity, with large standard deviation and wide fluctuation in effects. Spatially, strong positive correlations are found in Haxi Subdistrict, the Yingbin Road Concentration Zone, and HETDZ, while strong negative correlation appears in the east riverside area. In Haxi, proximity to Harbin Institute of Technology (HIT) and science parks supports big data enterprise growth, forming a feedback loop with universities via joint labs and talent pipelines. Hulan District, with low-cost land and idle industrial spaces, supports the expansion of e-commerce and light-asset internet firms. The Yingbin Road Concentration Zone, leveraging airport and highway access, supports smart logistics innovations. The HETDZ has repurposed old factories into coworking spaces, attracting SMEs. In contrast, the east riverside area, dominated by heavy industries and aging demographics, lacks innovation synergy with internet technologies.

The variable Distance between nearest universities/research institutes and center point has a high absolute average negative value and a large standard deviation, indicating strong influence. Most areas show a negative correlation, especially near top institutions like the Yingbin Road Concentration Zone, Songbei Science and Technology Innovation City, Jiangbei University Town, and HETDZ, where proximity enhances access to talent and resources. As distance increases, innovation density drops due to reduced collaboration and resource access. However, positive correlations appear in areas like the South New Industrial Area, where national policies have led to independent industry clusters (e.g., biomedicine, high-end equipment). These regions rely less on universities, instead developing in-house R&D systems. Distant zones also serve as R&D or production bases, benefiting from lower costs and abundant land.

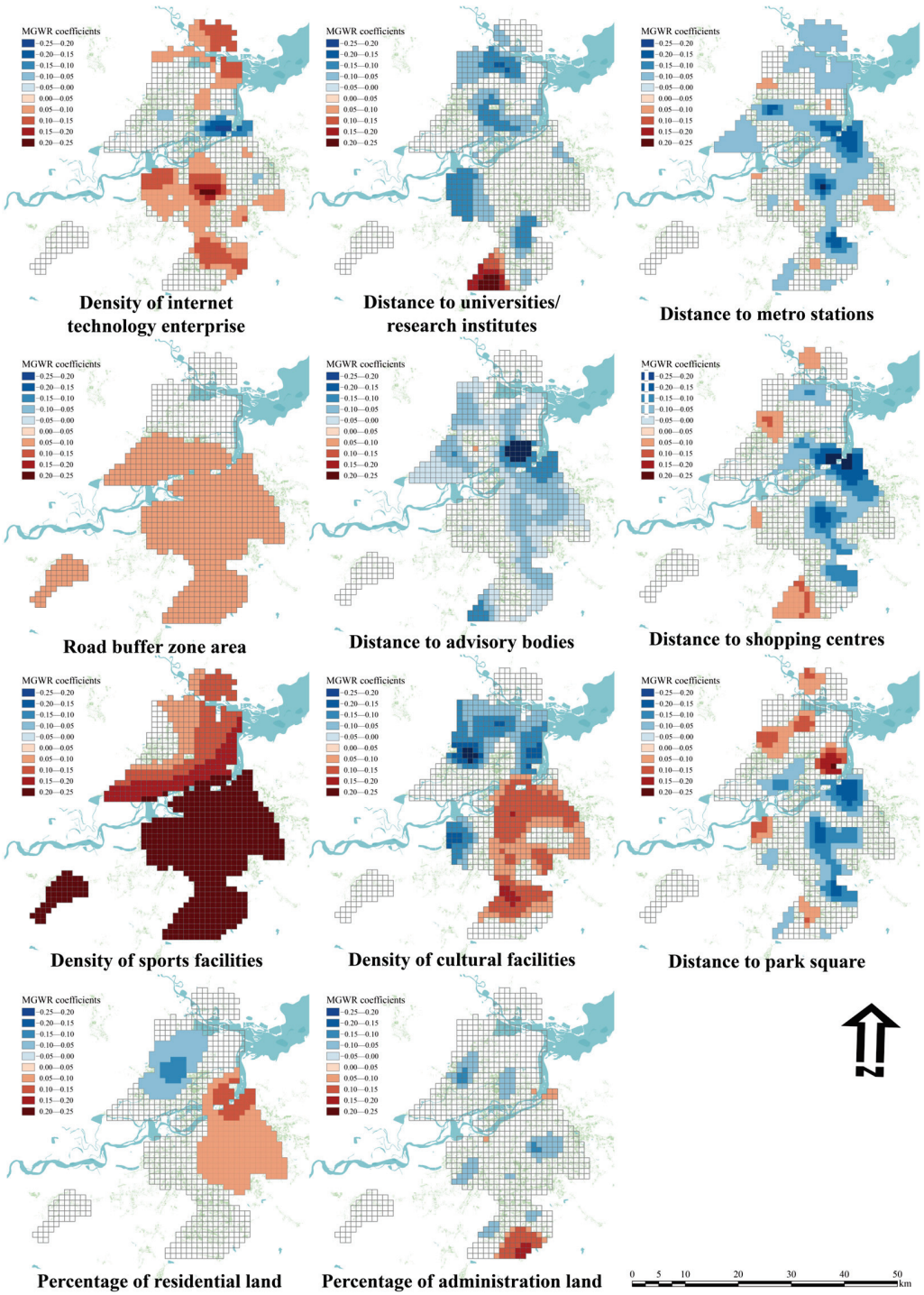

Figure 10. Spatial distribution of spatial influences on innovation as a result of MGWR analyses.

② Infrastructure support factors

- Transport facility factors

The variable Distance between nearest metro stations and center point shows a high standard deviation, negative average, and large absolute correlation coefficient, indicating that proximity to metro stations significantly promotes innovation space density. This is evident in the east riverside area (Line 1 terminal), in central Nangang District (intersection of Lines 1 and 2), in the HETDZ (Line 1 terminal), and near Jiangbei University Town (Line 2 terminal). These locations effectively transform metro passenger flow into innovation momentum, with compatible surrounding land uses. For instance, the east riverside

area anchors metro access to revitalized industrial heritage, attracting digital design and cultural tech firms. Central Nangang forms a "10 min professional service circle" around its metro node, serving the legal and financial needs of innovation enterprises. The HETDZ integrates metro, freight rail, and highways into a multimodal hub, while Jiangbei's station connects multiple campuses to the Science and Technology Innovation City of Songbei.

The Road buffer zone variable (500 m buffer from major roads) shows low heterogeneity and weak but stable positive correlation. Its influence is globally distributed and has a moderate positive impact in areas south of the Songhua River and some developed northern zones. Major roads serve as logistics and commuting backbones, lowering innovation transaction costs (e.g., raw material transport, commuting). However, the effect varies by industry and development intensity. Since Harbin's road network coverage and supporting infrastructure are relatively consistent along major corridors, the influence remains modest and geographically widespread. In sparsely developed northern Songbei, with fewer roads, the influence on innovation is negligible.

- Innovation support facility factors

The variable Distance between nearest advisory bodies and center point also has a large standard deviation, and its negative correlation indicates that closer proximity to consulting services fosters innovation. The Songpu Group in Songbei District exhibits a strong positive core, where consulting agencies significantly support innovation. As Harbin New District's core, Songpu hosts biomedicine, digital economy, and aerospace sectors, with strong reliance on services like patent agencies and cross-border auditing, enhanced by spatial closeness. Urban design aligns tightly with agency service coverage through dense street grids, keeping innovation spaces within their service radius. The Songbei International Financial Tower, for example, adopts a vertically integrated model, enabling onsite access to contract notarization and investment services, greatly reducing time costs.

③ Public service support factors

- Catering and shopping facility factors

Large shopping centers, as living circle cores, are vital innovation space support facilities. The variable Distance between nearest shopping centers and center point has high standard deviation and marked heterogeneity. Its impact is generally negative—closer proximity corresponds to higher innovation space density. This is evident near east industrial parks, the Historical Area central science and technology parks, and the northern part of the HETDZ, where co-location of shopping centers and tech parks facilitates commercial–innovation synergy. These centers offer convenience services and business functions (e.g., conference venues), drawing in tech enterprises and talent. However, in areas like the South New Industrial Area, with fewer shopping centers and stronger policy reliance, innovation follows a "low-dependence" model. Here, high land prices may even hinder innovation, inverting the relationship between shopping centers and innovation spaces.

- Cultural and Leisure Facility Factors

Density of sports facilities shows a strong positive effect on central innovation spaces, especially south of the Songhua River, with a gradient decline northwestward. Sports venues are often integrated with commercial and innovation zones and paired with talent apartments, enhancing livability and attracting professionals. They may also support informal cross-industry exchanges, potentially fostering tacit knowledge spillovers. North of the river, sports facility density and impact drop sharply due to geographic separation, forming a rigid "south strong, north weak" boundary.

The Density of cultural facilities variable shows large fluctuations and both strong positive and negative correlations across areas. Positive effects appear in the Historical Area and Pingfang District, where heritage sites like Central Street and St. Sophia Cathedral and reused Soviet factories attract culture–tech hybrid enterprises. These "productive" cultural spaces boost innovation through storytelling and knowledge sharing. In contrast, Songbei District's and Qunli Subdistrict's cultural facilities (e.g., Ice and Snow World) function more as tourist attractions. Large commercial uses and parking displace innovation space, while high-end consumption facilities in Qunli raise land costs, suppressing innovation clusters. Thus, cultural spaces reflect sharp spatial heterogeneity—productive ones support innovation, while consumer-oriented ones may hinder it.

The variable Distance between nearest park square and center point shows a relatively uniform scatter pattern in relation to innovation spaces, aligning with Harbin's "multi-core group" model. Parks like Sun Island, Cultural Park, and Children's Park act as local innovation growth poles. These areas, with quality landscapes and open spaces, improve livability and attract highly educated talent. As informal public nodes, parks encourage interdisciplinary interaction and tacit knowledge exchange. Their influence radius averages under 3 km, corresponding to the 15 min living circle range; beyond that, use declines. In some zones, underground areas and expressways slightly expand the effective radius but weaken impact strength. In Qunli, green spaces mainly serve residential needs, while in Songbei, greenery is tied to eco-tourism, leading to lower innovation utility due to mismatched functions.

④ Space carrier characterization factors

MGWR results show that while the land use mix ratio has no significant influence on innovation density, the proportion of specific land types does. Residential land shows strong positive effects, notably in the central and eastern Historical Area. Conversely, negative impacts appear near the Li-min Pharmaceutical Core Zone and Jiangbei University Town. Administration land shows mixed effects, suppressing innovation in some areas but supporting it where vocational schools cluster. Harbin's strict functional zoning limits mixed-use development, keeping mixed-use advantages theoretical. Innovation tends to concentrate in isolated plots, with weak association with adjacent land functions; thus, the land mix ratio variable remains insignificant. However, in the Historical Area, higher residential density supports embedded small and micro innovation firms through integrated communities. These zones also enable informal innovation venues such as shared offices and cafés, fostering cross-industry exchange. In contrast, new districts mainly feature enclosed residential blocks lacking commercial or industrial functions, producing a "sleeping city effect" where innovation firms relocate due to inadequate support services. Administration land, due to its own complex land type, positively contributes in Pingfang District, where vocational schools cluster near aviation and auto industries. Specialized education and surrounding research land cultivate technical talent, promoting workshop-level innovation. Yet, some administrative centers and large hospitals, though occupying prime locations, have limited service radii and constrain space for innovation carriers, generating localized negative impacts.

4. Discussion

4.1. Exploration of the Mechanism of Influencing Factors

The formation of urban innovation space displays significant regional heterogeneity. While commonly influenced by transportation networks and knowledge spillover, it is also closely tied to local industrial bases, policy direction, and spatial carrier attributes. This study builds an influencing factor system based on empirical analysis in Harbin,

examining innovation entities, infrastructure, public services, population and market, and spatial carriers. However, insights from a single city cannot fully explain the complexity of innovation space evolution across China. Thus, this paper draws comparative references from cities such as Nanjing and Shenzhen and systematically compares shared influencing factors.

Multicity research consistently confirms transportation networks as critical to innovation space. In Harbin, proximity to metro stations has a strong positive impact on innovation density, while the road buffer zone shows limited coverage. The metro effect is concentrated at the intersection of Line 1 and Line 2 in mature commercial districts; peripheral stations lack influence due to single-function settings. In Nanjing, bus stop density and proximity to main roads significantly drive innovation clustering, demonstrating balanced support through its "multi-center + axial belt" structure [36]. In Shenzhen, the effect of public transport and transport hubs intensifies alongside industrial upgrading, overtaking manufacturing after 2015, reflecting a transition from logistics to talent commuting [52]. Transport accessibility reduces flow costs, enabling knowledge spillover and resource integration, forming fundamental conditions for innovation space. However, its efficacy depends on station density and the surrounding industry mix. Harbin's sparse network and fragmented functions limit this effect, while Nanjing and Shenzhen realize citywide support through dense infrastructure and integrated transport–industrial development.

The livability factor has gained importance in multi-scale studies. In Harbin, innovation space density increases near large shopping centers, though some areas show a "reduced shopping center dependence" model. Nanjing identifies convenience store density and consumption space as top drivers, suggesting that third spaces foster informal interaction and innovation [36]. Later studies in Shenzhen reveal that medical and sports facilities play a growing role, particularly among younger talent, reflecting rising demands for health and work–life balance [52]. This indicates that innovation spaces must balance basic services with higher-order livability to attract skilled professionals. Harbin's facilities are improving but lack sufficient coverage. Nanjing achieves widespread access through convenience services, while Shenzhen focuses on meeting generational quality demands.

The proximity of universities and research institutes has varying impacts. In Harbin, innovation density declines with distance from universities, indicating strong spatial relevance. In Nanjing, the effect of university proximity is only moderately significant, with that of proximity to research institutions even less so [36]. In Shenzhen, the number of such institutions strongly correlates with innovation output [52]. These disparities may arise from differences in institutional openness. Harbin benefits from university–enterprise collaborations that harness proximity advantages. In contrast, Nanjing's institutional systems may limit knowledge spillover. Shenzhen excels through seamless integration of campuses and industrial parks, with numerous joint laboratories converting spatial proximity into innovation outcomes.

Ecological factors have a "double-edged sword" effect. In Harbin, park proximity shows mixed effects across regions. Natural landscapes in Nanjing hinder innovation clustering [36], while in Shenzhen, they promote it [52]. In Harbin's dense historical areas, parks enhance innovation by supporting the 15 min living circle. In contrast, green spaces in newer zones serve mainly residential or tourism functions, causing resource mismatches and limiting innovation. Nanjing's ecological zones, located at urban fringes and lacking supportive facilities, isolate innovation enterprises. Shenzhen, as a park city, embeds ecological elements into the dense urban fabric, merging industrial and ecological functions, underscoring how development stages affect the transformation of ecological value.

4.2. Planning Implications Based on Analysis Results

The Historical Area exhibits a dual challenge: the need to redevelop traditional industrial zones and the presence of innovation valleys, where technology transfer chains are long and infrastructure is underdeveloped. Enhancing the innovation capacity in these areas requires the renovation of old factories and the establishment of pilot test bases. Meanwhile, the ongoing role of research-oriented universities in fostering the aggregation and development of innovation activities should be fully leveraged. Considering differences among university types, targeted support should be provided in areas such as tax incentives, research funding, and intellectual property protection.

To address the spatial heterogeneity of the influence of universities and research institutions in New Town Area, an integrated University–Incubator–Industrial Park platform should be established, building on the existing concentration of financial institutions and infrastructure in the Songbei Ice City Science and Technology Corridor. This platform can facilitate the transfer of laboratory outcomes to enterprise R&D. Furthermore, government-guided funds should support characteristic industries such as biomedicine and artificial intelligence. By injecting capital, these measures can drive industrial development and technological innovation, creating an efficient innovation ecosystem primarily fueled by incremental growth.

In the Industrialized Park Area, with low innovation activity density and a greater distance from universities, where enterprises' independent innovation capabilities are relatively weak—such as the South New Industrial Area—it is essential to strengthen linkages between enterprise-led innovation and external research resources to offset geographic disadvantages. In innovation valleys with unclear functions and lagging infrastructure, such as the Yingbin Road Concentration Zone, a mix of policy instruments—including tax rebates, technology loans, rental subsidies, and talent incentives—can reduce the start-up and operational costs of small- and medium-sized technology enterprises, thereby promoting the agglomeration and development of innovative actors.

5. Conclusions

By applying methods such as KDE, ESDA, and DBSCAN to analyze the spatiotemporal evolution patterns of innovation activities in Harbin using 46,057 patent application data, and constructing a multidimensional influencing factor system through the MGWR model, this study found the following:

The spatial distribution of innovation space in Harbin shows a "one core, four clusters" structure, with the core area of high innovation density located around the Dazhi Street in Nangang District, where Harbin Institute of Technology and Harbin Engineering University are located. The "four clusters" mainly include industrial park carriers such as the Limin Pharmaceutical Core Zone in Hulan District, the Science and Technology Innovation City of Songbei District, the Yingbin Road Concentration Zone, and the Harbin Economic and Technological Development Zone (HETDZ), which exhibit relatively low-density distribution characteristics. Harbin's innovation space is gradually evolving from a single-center agglomeration to a multi-center cluster model, with industrial park clusters such as the HETDZ forming new innovation growth poles, showing a growth trend that expands from the center to the periphery. Key universities and high-tech enterprises have become the main bodies of innovation activities. The spatial distribution of innovation subjects has gradually expanded from the concentration of key universities in the Historical Area to new innovative spaces in peripheral areas such as the Industrialized Park Area and New Town Area.

The spatial pattern of innovation in Harbin appears to be associated with a nonlinear interaction among innovation entities, infrastructure, public services, and spatial carriers,

with significant spatial heterogeneity in the intensity and direction of these factors. Among the innovation subjects, the proximity of internet technology enterprises and universities/research institutes to innovation density shows a polarization effect due to differences in regional industrial foundations and policy orientation. In terms of infrastructure, metro stations and major roads play a global supporting role by reducing element flow costs, but their effects in peripheral areas are weak due to the maturity of supporting facilities. In terms of public service facilities, sports and cultural facilities stimulate innovation vitality through social networks and scenario integration, while factors such as shopping centers and park squares have a bidirectional effect in different regions due to functional mismatches. Compared with cities like Wuhan, Nanjing, and Shenzhen, it was found that transportation networks, convenience of life, and proximity to universities are common driving factors. However, Harbin is still limited by road network density, functional fragmentation, and insufficient industry–academia–research collaboration, and therefore needs to optimize spatial carriers and apply precise policy regulation to improve the efficiency of innovation factor integration.

Urban innovation space is a powerful driving force and efficient engine for urban development. Its pattern is no longer a single structure, but rather a complex structure with highly concentrated and uneven distribution. Analyzing the evolution of the spatial pattern of innovation space and its influencing factors in Harbin, summarizing the development law of innovation activities in time and space, and establishing a system of influencing factors allow for the discovery of potential growth spaces and a clearer understanding of the generation and development mechanisms of innovation space, and provide a reference for the future development of urban innovation space.

This study uses patent application data as a representative of innovation activities, which has certain limitations. The construction of the influencing factor indicator system is mostly based on POI data and land use classification data. Further analysis will require supplementation with global policies and other richer variable data. In addition, when implementing the influencing factors of innovation space in spatial scales, the research range is divided into grid scales. Although existing research has confirmed that a 1 km $\times$ 1 km scale is optimal, there is still a boundary uncertainty that affects the accuracy of research results. Therefore, this paper only provides an initial analysis of innovation activity space in Harbin, and future research needs to further refine the data representing urban innovation activities and improve related studies.

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Data Availability Statement: The original data presented in the study are openly available at https://www.patsnap.com/.

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

Abbreviations

The following abbreviations are used in this manuscript:

HETDZ	Harbin Economic and Technological Development Zone
HIT	Harbin Institute of Technology
HEU	Harbin Engineering University
KDE	Kernel Density Estimation
ESDA	Exploratory Spatial Data Analysis
DBSCAN	Density-Based Spatial Clustering of Applications with Noise

References

1. Zou, Z.; Zhou, R.; Jiao, K.; Yang, H.; Wu, T.; Hu, C. Economic Downturn and Climate Change: Mapping Spatial Heterogeneity of Socio-Economic Vulnerability for a Complex Future Scenario. *Int. J. Disaster Risk Reduct.* **2025**, *130*, 105875. [CrossRef]
2. Li, L.; Zhang, X.; Luo, Y. Esearch on the Evolution Characteristics of Innovation Space from an Output Perspective: A Case Study of Shanghai. *Urban Dev. Stud.* **2019**, *26*, 87–92+33.
3. Kerr, W.R.; Robert-Nicoud, F. Tech Clusters. *J. Econ. Perspect.* **2020**, *34*, 50–76. [CrossRef]
4. Kerr, W.R.; Kominers, S.D. Agglomerative Forces and Cluster Shapes. *Rev. Econ. Stat.* **2015**, *97*, 877–899. [CrossRef]
5. Audretsch, D.B.; Feldman, M.P. R&D Spillovers and the Geography of Innovation and Production. *Am. Econ. Rev.* **1996**, *86*, 630–640.
6. Fischer, M.M.; Nijkamp, P. *Handbook of Regional Science*; SpringerLink: Berlin, Germany, 2021.
7. Ciccone, A.; Hall, R. *Productivity and the Density of Economic Activity*; National Bureau of Economic Research: Cambridge, MA, USA, 1993; p. w4313.
8. Buzard, K.; Carlino, G.A.; Hunt, R.M.; Carr, J.K.; Smith, T.E. Localized Knowledge Spillovers: Evidence from the Spatial Clustering of R&D Labs and Patent Citations. *Reg. Sci. Urban Econ.* **2020**, *81*, 103490. [CrossRef]
9. Moreno, R.; Paci, R.; Usai, S. Geographical and Sectoral Clusters of Innovation in Europe. *Ann. Reg. Sci.* **2005**, *39*, 715–739. [CrossRef]
10. Lim, U. The Spatial Distribution of Innovative Activity in U.S. Metropolitan Areas: Evidence from Patent Data. *J. Reg. Anal.* **2003**, *33*, 97–98. [CrossRef]
11. Fornahl, D.; Brenner, T. Geographic Concentration of Innovative Activities in Germany. *Struct. Change Econ. Dyn.* **2009**, *20*, 163–182. [CrossRef]
12. Figueiredo, O.; Guimarães, P.; Woodward, D. Industry Localization, Distance Decay, and Knowledge Spillovers: Following the Patent Paper Trail. *J. Urban Econ.* **2015**, *89*, 21–31. [CrossRef]
13. Jaffe, A.B.; Trajtenberg, M.; Henderson, R. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. *Q. J. Econ.* **1993**, *108*, 577–598. [CrossRef]
14. Rosenthal, S.S.; Strange, W.C. Geography, Industrial Organization, and Agglomeration. *Rev. Econ. Stat.* **2003**, *85*, 377–393. [CrossRef]
15. Balland, P.-A.; Boschma, R.; Frenken, K. Proximity and Innovation: From Statics to Dynamics. *Reg. Stud.* **2015**, *49*, 907–920. [CrossRef]
16. Carlino, G.; Kerr, W.R. Chapter 6—Agglomeration and Innovation. In *Handbook of Regional and Urban Economics*; Duranton, G., Henderson, J.V., Strange, W.C., Eds.; Elsevier: Amsterdam, The Netherlands, 2015; Volume 5, pp. 349–404.
17. Audretsch, D.B. Agglomeration and the Location of Innovative Activity. *Oxf. Rev. Econ. Policy* **1998**, *14*, 18–29. [CrossRef]
18. Glaeser, E.L. Learning in Cities. *J. Urban Econ.* **1999**, *46*, 254–277. [CrossRef]
19. Teece, D.J. Towards an Economic Theory of the Multiproduct Firm. *J. Econ. Behav. Organ.* **1982**, *3*, 39–63. [CrossRef]
20. Bagella, M.; Becchetti, L. The "Geographical Agglomeration-Private R&D Expenditure" Effect: Empirical Evidence on Italian Data. *Econ. Innov. New Technol.* **2002**, *11*, 233–247. [CrossRef]
21. Love, J.H.; Roper, S. Location and Network Effects on Innovation Success: Evidence for UK, German and Irish Manufacturing Plants. *Res. Policy* **2001**, *30*, 643–661. [CrossRef]
22. Berliant, M.; Reed, R.R.; Wang, P. Knowledge Exchange, Matching, and Agglomeration. *J. Urban Econ.* **2006**, *60*, 69–95. [CrossRef]
23. Fallick, B.; Fleischman, C.A.; Rebitzer, J.B. Job-Hopping in Silicon Valley: Some Evidence Concerning the Microfoundations of a High-Technology Cluster. *Rev. Econ. Stat.* **2006**, *88*, 472–481. [CrossRef]
24. Tan, J. Growth of Industry Clusters and Innovation: Lessons from Beijing Zhongguancun Science Park. *J. Bus. Ventur.* **2006**, *21*, 827–850. [CrossRef]
25. Porter, M.E. *Harvard Business Review*; Harvard Business Publishing: Brighton, MA, USA, 1998.

26. Boschma, R.; Eriksson, R.H.; Lindgren, U. Labour Market Externalities and Regional Growth in Sweden: The Importance of Labour Mobility between Skill-Related Industries. *Reg. Stud.* **2014**, *48*, 1669–1690. [CrossRef]
27. Duan, J.; Zhu, L. Analysis of Creative Industry Parks' Spatial Evolution, Its Agglomeration Characteristics and Influence Factors: A Case Study of Shenzhen. *Mod. Urban Res.* **2015**, 76–82.
28. Meng, G.; Lyu, L.; Huang, R. The Characteristics of Location Selection and Influencing Factors of "Maker-Space" in Beijing. *J. Cap. Univ. Econ. Bus.* **2016**, *18*, 89–97.
29. Luan, F.; He, Y.; Zhang, Y. Spatial Characteristics of Cultural and Creative Industry Agglomerations and the Planning Guidance: Analysis Based on Enterprise Location in the Shanghai Central City. *Urban Plan. Forum* **2019**, 40–49.
30. Duan, D.; Du, D.; Liu, C. Spatio-Temporal Evolution of Urban Innovation Structure Based on Zip Code Geodatabase: An Empirical Study from Shanghai and Beijing. *ACTA Geogr. Sin.* **2015**, *70*, 1911–1925. [CrossRef]
31. Wang, J.; Sun, Y.; Lin, N. Spatial-Temporal Evolution Characteristics and Countermeasures of Urban Innovation Activities Distribution Pattern: A Case Study of Hangzhou. *Urban Dev. Stud.* **2020**, *27*, 12–18+29.
32. Esmaeilpoorarabi, N.; Yigitcanlar, T.; Guaralda, M. Place Quality in Innovation Clusters: An Empirical Analysis of Global Best Practices from Singapore, Helsinki, New York, and Sydney. *Cities* **2018**, *74*, 156–168. [CrossRef]
33. Esmaeilpoorarabi, N.; Yigitcanlar, T.; Guaralda, M.; Kamruzzaman, M. Does Place Quality Matter for Innovation Districts? Determining the Essential Place Characteristics from Brisbane's Knowledge Precincts. *Land Use Policy* **2018**, *79*, 734–747. [CrossRef]
34. Esmaeilpoorarabi, N.; Yigitcanlar, T.; Guaralda, M.; Kamruzzaman, M. Evaluating Place Quality in Innovation Districts: A Delphic Hierarchy Process Approach. *Land Use Policy* **2018**, *76*, 471–486. [CrossRef]
35. Yang, C.; Yang, H.; Han, H.; Yang, G. Spatial Distribution Pattern and Influencing Factors of Innovation Andknowledge-Intensive Services Based on POl Data: A Case Study of Hefei, China. *Geogr. Res.* **2023**, *42*, 682–698.
36. Guan, M.; Sun, S. Agglomeration Characteristics and Influencing Factors of Urban Innovation Space: A Case Study of Nanjing Main City. *City Plan. Rev.* **2023**, *47*, 21–31.
37. Zhou, R.; Qiu, Y.; Hu, Y. Characteristics, Evolution and Mechanism of Inter-City Innovation Network in China: From a Perspective of Multi-Dimensional Proximity. *Econ. Geogr.* **2021**, *41*, 1–10.
38. Sun, Y.; Fan, J.; Liu, H.; Zhao, T. Spatial and Temporal Pattern of Digital Technology Innovation and Its Influencing Factors in the Yangtze River Delta. *Econ. Geogr.* **2022**, *42*, 124–133.
39. Wu, K.; Ye, Y.; Zhang, H.; He, Z.; Wang, X.; Zheng, Z. The Geographical Pattern and Diversity of Strategic Industry Technological Innovation in the Guangdong-Hong Kong-Macao Greater Bay Area. *Trop. Geogr.* **2022**, *42*, 183–194.
40. Huang, L.; Huang, J.; Xu, J. Research on the Spatial Evolution and Trend of R&D Innovation in Shanghai from the Perspective of Patent Analysis. *Urban Rural Plan.* **2020**, *4*, 70–79.
41. Ciccone, A. Agglomeration Effects in Europe. *Eur. Econ. Rev.* **2002**, *46*, 213–227. [CrossRef]
42. Yang, X.; Ren, S.; Jin, H. Spatial Differentiation and Spillover Effect of Urban Innovation Space in China: Based on the Panel Data of 287 Prefecture-Level Cities. *Econ. Geogr.* **2023**, *43*, 52–61.
43. Lyu, L.; Zhao, C. Review and Prospect of the Urban Innovation Geography of China. *Econ. Geogr.* **2021**, *41*, 16–27.
44. Sun, Y.; Li, G.; Yuan, W.; Sun, T. The Spatial Concentration of Innovation and Its Mechanisms: A Literature Review and Prospect. *Hum. Geogr.* **2017**, *32*, 17–24.
45. Zhang, X.; Du, L.; Song, X. Identification of Urban Renewal Potential Areas and Analysis of Influential Factors from the Perspective of Vitality Enhancement: A Case Study of Harbin City's Core Area. *Land* **2024**, *13*, 1934. [CrossRef]
46. Ning, J.; Ma, H.; Sun, Y.; Wang, N.; Wang, M. Research on the Characteristic Identification and Multidimensional Dynamic Evolution of Urban–Rural Fringe in Harbin, China. *Land* **2025**, *14*, 359. [CrossRef]
47. Wang, Y.; Han, Y.; Pu, L.; Jiang, B.; Yuan, S.; Xu, Y. A Novel Model for Detecting Urban Fringe and Its Expanding Patterns: An Application in Harbin City, China. *Land* **2021**, *10*, 876. [CrossRef]
48. Zou, Z.; Zhou, R.; Jiao, K.; Guo, C. Assessment of Socio-Economic Vulnerability to Disaster Risks in Shrinking Cities of Northeast China: A Case Study of Harbin. *Trans. Urban Data Sci. Technol.* **2025**, *4*, 157–176. [CrossRef]
49. Tang, K.; Zhai, G.; He, Z.; Gu, F. The Study on the Spatio-Temporal Distribution Patterns andEvolution Mechanism of Makerspaces in Nanjing. *Mod. Urban Res.* **2019**, 52–59.
50. Li, Y.; Zhong, J.; Zeng, X. Comparative Analysis of Factors Affecting the Location of Maker Space: A Case Study on Fuzhou and Shenzhen. *South Archit.* **2020**, 49–55.
51. Liu, J.; Zhen, F.; Zhang, S.; Kong, Y.; Li, Z. Spatial Distribution Characteristics and Influencing Factors of New-Generation Information Technology Companies: A Case of Nanjing Central City. *Econ. Geogr.* **2022**, *42*, 114–123+211.
52. Wang, B.; Xie, J.; Wang, L. Evolution of Urban Innovation Space and Influencing of Innovation Environment Elements on Innovation Outputs: Evidence from Shenzhen. *Econ. Geogr.* **2024**, *44*, 84–90.
53. Zhang, Y.; Liu, J.; Zhou, L.; Wang, Y.; Li, P. Cluster Identification and Spatial Characteristics Analysis of Shunfeng Express Service Facilities Based on the DBSCAN Algorithm in Beijing. *J. Geo-Inf. Sci.* **2020**, *22*, 1630–1641.

54. Shen, L.; Zhang, C.; Li, H.; Wang, Y. Interaction between Commuting Modes and Job-Housing Imbalance in Metropolis: An Empirical Study by Bayesian-Tobit Analysis in Beijing. *Prog. Geogr.* **2018**, *37*, 1277–1290.
55. Wang, R. How Do Patent Subsidies Drive SMEs to Patent? Evidence from China. *J. Dev. Eff.* **2024**, *16*, 408–427. [CrossRef]

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Mapping Green Space Inequalities in 26 European Cities

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Abstract: Urban green spaces are a crucial element of sustainable urban development, but their uneven distribution exacerbates socio-spatial inequalities within cities. This study analyses spatial inequalities in the distribution and accessibility of urban green spaces in 26 European capitals, introducing the composite Urban Green Equity Index. The index incorporates three fundamental dimensions, availability, accessibility and need, aiming to provide
a comprehensive picture of environmental inequalities in the urban fabric. The index is composed of seven variables including the percentage of green space, green space per capita, average access time, access time range, population density and the percentages of children and elderly people. Free geospatial and demographic data were used to calculate the variables. The variables were grouped into the corresponding thematic dimensions and then Principal Component Analysis was applied to compose the individual axes, based on which the composite index was calculated. The results were mapped and revealed strong inter-regional and intra-city differences, with Northern European cities showing higher equality compared to those in the South. The study highlights the importance of integrating socio-demographic indicators into urban planning and concludes that the assessment of urban green space requires a holistic, socially sensitive and methodologically sound approach for a just transition to sustainable cities.

Keywords: urban green spaces; spatial analysis; Geographical Information Systems; green justice; environmental equity; spatial inequalities

1. Introduction

Urban Green Spaces (UGS), such as parks, urban forests, gardens, and green corridors, are a critical element of sustainable urban development, as they offer a range of environmental, social, and health benefits to city dwellers [1–3]. UGS contribute to reducing temperatures through heat absorption, improving air quality, reducing noise, supporting biodiversity, and enhance the physical and mental well-being of urban residents [1,4,5]. In the context of rapid urbanization, the equitable distribution and accessibility of green spaces have become central to discussions on environmental justice and sustainable urban development [6].

Despite their benefits, UGS are not distributed equitably within cities, and often reflect or reinforce existing socio-spatial inequalities [7–9]. The debate on environmental justice in urban space has emerged as one of the key scientific and political issues of the 21st century, especially in the light of climate change, urbanization, and increasing social inequality. Equitable distribution and access to urban green spaces are now recognized indicators of social and environmental well-being [10,11].

The term "green justice" refers to equal access to quality green spaces, regardless of social status, age, or other demographic characteristics [11]. Studies have shown that socially

vulnerable groups, such as low-income populations, children, and the elderly, are often underserved, as they live in areas with limited or difficult access to green spaces [12,13].

Traditional urban planning has often ignored the social dimension of green space distribution, focusing only on the total green area or the presence of parks. However, recent studies support a multifactorial approach, which takes into account not only spatial distribution, but also social need and accessibility [14].

This "green inequality" has emerged as a critical challenge for urban planners and policymakers seeking to promote inclusive, equitable, and sustainable cities [15,16]. Thus, in recent years, there has been growing interest in assessing the distribution and accessibility of urban green space using social criteria, with the aim of identifying inequalities related to the location, population density, and socio-demographic characteristics of residents. To capture these inequalities, scholars have developed multidimensional frameworks that assess green equity along three main dimensions: availability, accessibility, and need [17–20].

Availability primarily refers to the amount of green space in a given urban area, often expressed through metrics such as green space per inhabitant or the percentage of green space per administrative unit. These indicators offer a first-level approximation of how much green space is available to city dwellers [18].

Accessibility concerns the proximity and ease with which people can reach green spaces [21]. The World Health Organization (WHO) recommends that every citizen should live within 300 m (5 minutes' walk) of accessible green spaces [2], but this target remains unmet in many urban settings. The quality of walking infrastructure, physical barriers (such as highways or railways), and entry restrictions can significantly influence perceived and actual access. Inequalities within neighborhoods are particularly significant in large cities, where average accessibility can mask strong internal inequalities. Geospatial analyses using Geographical Information Systems (GIS) technologies have enabled detailed assessments of walking access, allowing for a more accurate assessment of the equity of green spaces [22–24].

The need dimension relates to demographic and social characteristics that indicate increased demand for or dependence on green spaces, particularly among vulnerable populations. Common indicators include population density, the proportion of children, and the proportion of elderly residents, groups that are more likely to benefit from nearby green spaces for recreation, socialization, and health [17,25]. High-density urban areas typically experience increased demand for public green spaces, but often suffer from lower provision, exacerbating inequality [26]. Children and the elderly are particularly vulnerable to local accessibility due to limited mobility and specific health needs [25]. Incorporating demographic indicators into spatial assessments is therefore crucial for understanding who is most deprived of green space.

Recent efforts in green justice research have focused on mapping the intersection of sociodemographic vulnerability and spatial green deficits through composite indicators and vulnerability indices [22,27]. Thus, the measurement of green inequality has evolved from simple indicators of green cover to complex models that combine geospatial, social, and access data. The combination of these dimensions is considered essential for understanding environmental (in)equality in the urban fabric.

In Europe, the European Commission has highlighted the importance of green infrastructure through strategies such as the EU Biodiversity Strategy for 2030 [28], which calls for "bringing nature back into our lives" and improving access to green spaces, especially in urban environments. Similarly, the European Environment Agency (EEA) has highlighted the need for spatially explicit assessments of green space provision, particularly in light of increasing socio-economic inequalities and urban density [29].

Comparisons between European cities have revealed clear geographical trends in the distribution of UGS. Northern and Central European cities tend to have higher overall green coverage and more equitable access, compared to Mediterranean and Eastern European cities, which exhibit high inequalities, low green density, and fragmented spaces [29]. These differences are not only geographical but also institutional, as they are linked to the presence or absence of long-term urban planning and green strategies. However, the comparative assessment of "green justice" at the intra-city level between European cities remains limited [30], mainly due to the lack of harmonized data and multifactor measurement tools.

In this context, this study aims to develop and implement a composite Urban Green Equity Index (UGEI) in 26 European capitals. This index is based on three main axes, (a) the availability of green spaces, (b) their accessibility, and (c) social need, as expressed by population density and the composition of vulnerable age groups. Through the UGEI, the research aspires to capture the multidimensional spatial inequalities in urban green spaces in a holistic way, contributing to the empirical documentation of environmental (in)equality in European urban space. This research provides the first harmonized and comparative assessment of urban green space inequalities across European capitals. By systematically mapping spatial inequalities in the distribution of green spaces, this study contributes to the growing literature on environmental justice in urban Europe and offers actionable insights for local government policies, promoting just green transitions.

2. Materials and Methods

This study focuses on 26 European capitals (Figure 1) (Amsterdam, Athens, Berlin, Bern, Bratislava, Brussels, Bucharest, Budapest, Copenhagen, Dublin, Lisbon, Luxembourg, Madrid, Oslo, Paris, Prague, Riga, Rome, Sofia, Stockholm, Tallinn, Valletta, Vienna, Vilnius, Warsaw, and Zagreb), for which urban green equity is examined through the construction of the composite index UGEI.

The selection of cities was based solely on the availability of harmonized and comparable data in the datasets used. The aim was to achieve the widest possible geographical coverage of Europe, rather than limiting the study to European Union member states.

The UGEI is a composite indicator that captures the spatial distribution of green space availability, accessibility, and population-based need, enabling an integrated assessment of UGS justice.

The UGEI was based on the synthesis of seven individual variables to assess the three thematic pillars of green justice (Table 1), and the methodological framework for its calculation is presented in Figure 2.

Table 1. Variables by pillar contributing to the composition of the UGEI.

Pillar	Variable
Availability	% UGS UGS per capita
Accessibility	Mean access to UGS Range of access to UGS
Need	Population density % population <15 years old % population over 65 years old



Figure 1. Study area: the 26 European capitals included in the analysis.

2.1. Data Sources and Description

The geographical delimitation of the analysis for each city was based on the set of "Urban Centres" as defined in the Global Human Settlement Database—Urban Centre Database (GHS-UCDB), developed by the European Commission's Joint Research Centre (JRC) within the framework of the Copernicus Emergency Management Service [31]. This dataset provides polygonal spatial entities representing the main urban formations of cities. The resulting area was used as a spatial filter to exclude all other data used in the subsequent analysis.

The Urban Atlas 2018 dataset [32] was used to estimate the UGS. From the set of categories, the thematic classes corresponding to "Green Urban Areas" and "Forests" were extracted, which represent the coverage of greenery found in urban areas.

To represent population characteristics, the census grid geospatial dataset of Eurostat GISCO (Geographic Information System of the Commission) was used, which is a polygon-based grid of 1 × 1 km covering the whole of Europe [33]. Each polygon contains information on the total number of inhabitants, as well as specific population groups such as children under 15 and elderly people over 65. The spatial data of this dataset (1 × 1 km grid) also constituted the spatial unit of analysis for this study.

In addition to the Urban Atlas, data from OpenStreetMap (OSM) were used to calculate accessibility to UGS. Linear data on the road network were extracted from OSM and used to estimate the travel time from each cell of the population grid to the nearest UGS area.

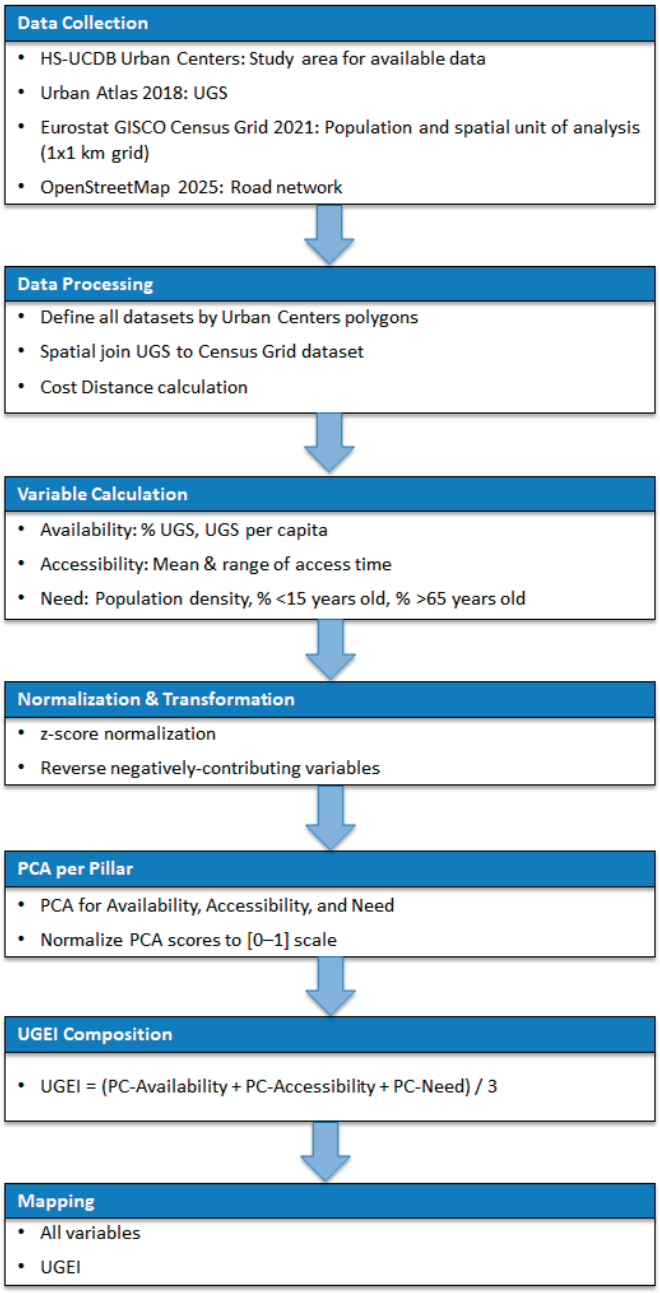

Figure 2. Methodology flowchart.

2.2. Spatial Analysis and UGEI Construction

All of the above data were transformed into the ETRS89-LAEA (EPSG:3035) reference system to ensure spatial compatibility and accuracy in the calculation of distances and areas.

The UGS area per capita was calculated by dividing the total UGS area within each grid polygon by the population of the polygon, while the percentage coverage of UGS (as a percentage of the total area of the polygon) was also calculated.

The calculation of the access time to the nearest UGS was based on pedestrian traffic on the road network, as in densely built-up urban environments, free direct access to green spaces is obstructed by natural and artificial barriers, such as buildings, fences, and private property. Therefore, the use of the road network provides a more realistic representation of accessibility as experienced by pedestrians.

The analysis focuses exclusively on pedestrian access, and an average walking speed of 4.8 km per hour was selected, a value widely used in the literature in relevant walkability studies [34,35]. This speed corresponds to the average walking speed of adults without mobility problems and is often used in spatial models of isochrone analyses.

The Cost Distance algorithm was used to estimate access time, which calculates the minimum cumulative "cost" (in this case, time) required to travel from any point on the surface to the nearest UGS. The spatial analysis of the cost surface was set at 1 m in order to accurately reflect the complexity of the urban fabric and the variation in distance on a small scale. The calculation included not only UGSs within the boundaries of urban centers, but also those located in neighboring areas outside urban boundaries, in order to realistically reflect residents' accessibility. In practice, city residents often have the opportunity to visit nearby green spaces that lie beyond the administrative or theoretically defined boundaries of the city. This ensured that the analysis captured residents' actual choices in relation to available UGS.

The analysis was applied to the entire area of urban centers for each capital, creating a continuous map of access time in minutes on the road network. Next, the average access time within each population grid and the access time range (the difference between the maximum and minimum values within the same polygon) were calculated as an indication of intra-spatial inequality within the grid, in order to record the unequal distribution of access among residents living in the same spatial context.

Finally, the total population density, the percentage of children under 15, and the percentage of elderly people over 65 per population grid were calculated. These variables highlight the social need for access to green spaces, both in terms of overall population concentration and the presence of vulnerable demographic groups.

The values of all variables were normalized using the z-score statistical transformation. In order to maintain a consistent direction in the calculation of the index, variables that are negatively related to the concept of equality in green spaces, i.e., those where an increase implies a deterioration (such as distance, population density, or the percentage of vulnerable groups), were inverted. The exception was variables that already express a positive contribution, such as UGS per capita and the UGS percentage.

Subsequently, Principal Component Analysis (PCA) was performed for each pillar with the aim of condensing multiple variables into a single axis that explains the maximum possible variance. For each pillar, only the first principal component that satisfied the Kaiser criterion (eigenvalue > 1) was retained. The values of the principal components were further normalized to the scale [0, 1] to make them comparable across pillars. To ensure that the resulting components were not affected by multicollinearity, a Variance Inflation Factor (VIF) analysis was conducted on the three principal components. The final composite UGEI was calculated as the average of the three normalized principal components corresponding to the pillars of availability, accessibility, and need.

For the UGEI, as for most variables, the average was also calculated, both at the city level and at the overall level, as a summary descriptive value, with the aim of facilitating the interpretation of the results and the comparison of values both within and among cities. An exception was the UGS per capita variable, for which the median was used as the central value due to the strong asymmetry in the value distribution.

Finally, all variables, as well as the composite UGEI, were mapped, allowing for a visual reading of spatial inequalities in access to urban green space both at the city level and within individual urban areas.

Spatial data analysis and mapping were performed using ArcMap 10.4 software, while PCA was performed using GeoDa 1.16.0.12.

3. Results

PCA was applied separately for the three pillars of the index, aiming to condense the respective variables into a single axis per pillar. In all pillars, only the component with an eigenvalue greater than 1 (Kaiser criterion) was retained, which captures the basic dimension of each theme and was used to calculate the composite UGEI (Table 2). For the availability pillar, the first component (eigenvalue = 1.221) explains 61% of the total variance and is characterized by an equal contribution of the variables % UGS and UGS per capita (loadings 0.707). In the accessibility pillar, the first component (eigenvalue = 1.692) explains 84.6% of the variance, with equal contributions from the mean and range of access time (loadings 0.707). Finally, for the need pillar, the first component (eigenvalue = 1.498, 49.9% variance) is mainly determined by the population under 15 years old (−0.705) and the population over 65 years (0.674), while the population density shows only a weak loading on this component (0.221).

Table 2. Principal Components Analysis results.

		PC1			PC2			PC3		
Pillar	**Variable**	**Eigen-Value**	**Prop. of Variance**	**Loadings**	**Eigen-Value**	**Prop. of Variance**	**Loadings**	**Eigen-Value**	**Prop. of Vari-ance**	**Loadings**
Availability	% UGS UGS per capita	1.221	0.610	0.707 0.707	0.779	0.390	0.707 −0.707	-		
Accessibility	Mean access to UGS Range of access to UGS	1.691	0.846	0.707 0.707	0.309	0.154	0.707 −0.707	-		
Need	Population density % population <15 years old % population over 65 years old	1.498	0.499	0.221 −0.705 0.674	0.994	0.332	0.955 0.016 −0.296	0.507	0.169	0.198 0.709 0.677

The VIF analysis that was conducted on the three principal components revealed that all VIF values were below 1.2, confirming the absence of excessive collinearity among the final indicators.

The mapping of UGEI and its variables indicates significant differences both among the cities and within them. The thematic maps present the conditions regarding the availability and accessibility of urban greenery, as well as the composition of the population, allowing for a comparative evaluation.

The distribution of the percentage of urban green space shows a marked spatial imbalance (Figure 3). The highest average value is recorded in Tallinn with 27.2%, followed by Amsterdam (24.7%) and Bern (24.1%), where there are contiguous areas with extensive UGS coverage. In contrast, the lowest average values are found in Athens (1.2%), Madrid (5.6%), and Paris (5.9%), which have either fragmented green spaces or areas almost lacking any UGS. Some cities, such as Bucharest, Paris, and Sofia, are characterized by a mosaic of variations, with areas of low and medium coverage coexisting without a clear spatial trend.

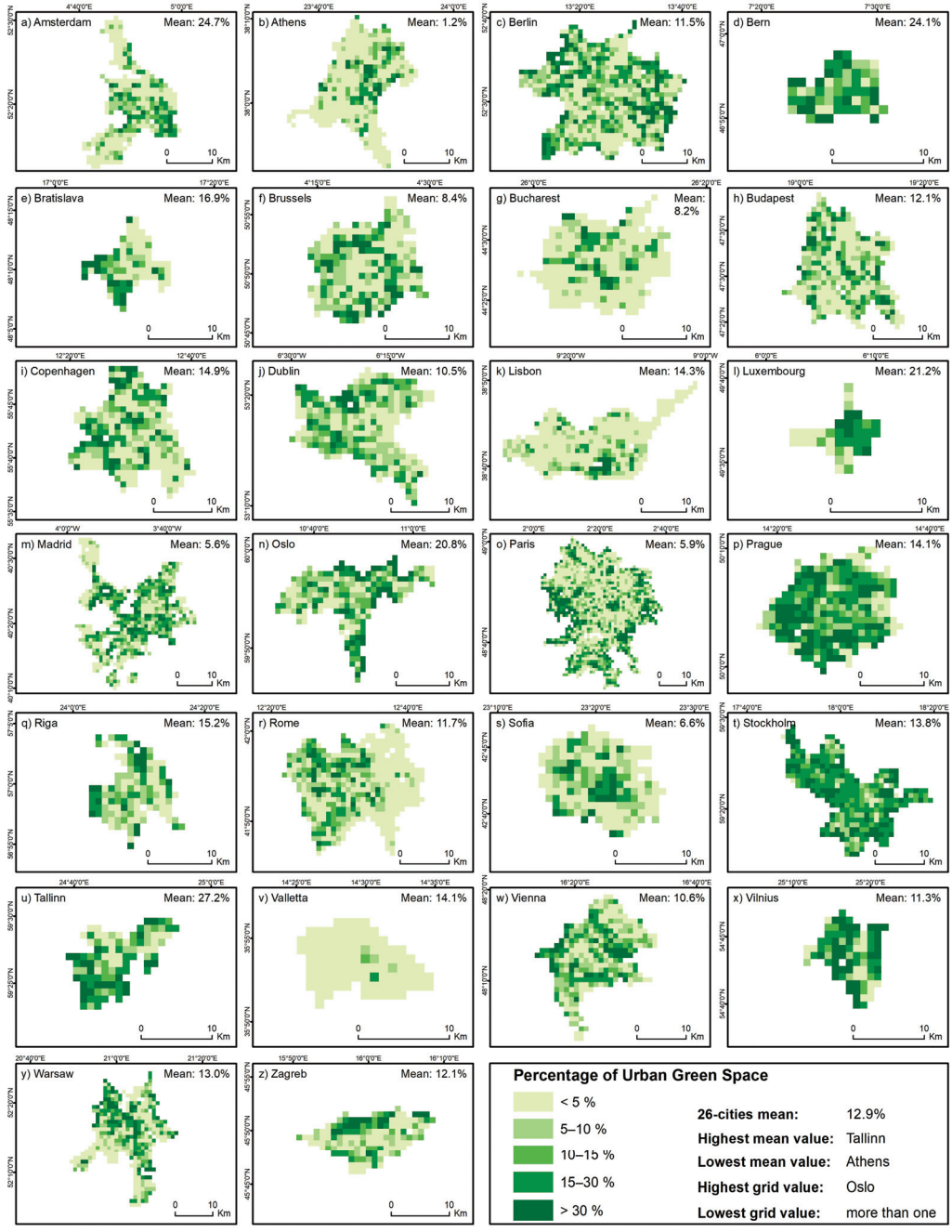

Figure 3. Percentage of UGS per city.

The UGS per capita reveals even more pronounced intra-urban and inter-city disparities (Figure 4). The average levels of the variable range from just 0.7 sq.m. per capita in Valletta to 66.3 sq.m. in Vilnius, demonstrating a difference of almost 95 times between the two extremes of the variable. High levels are also recorded in Tallinn (61.7 sq.m.)

and Stockholm (60.2 sq.m.), while in cities such as Bucharest (2.8 sq.m.), Lisbon (3.5 sq.m.) and Athens (3.6 sq.m.), the values remain extremely low. The average UGS per capita level for the 26 cities is 15.1 sq.m., with several European capitals falling below this threshold. At the intra-urban level, it is observed that in many cases, even cities with a relatively satisfactory overall UGS presence have areas with very low values per capita. The maps clearly show local phenomena of overconcentration of green space in areas with low population density, but also urban areas with minimal green space and high residential density. The gradation is pronounced in cities such as Berlin, Paris, Rome, and others, where areas with very low and very high values coexist.

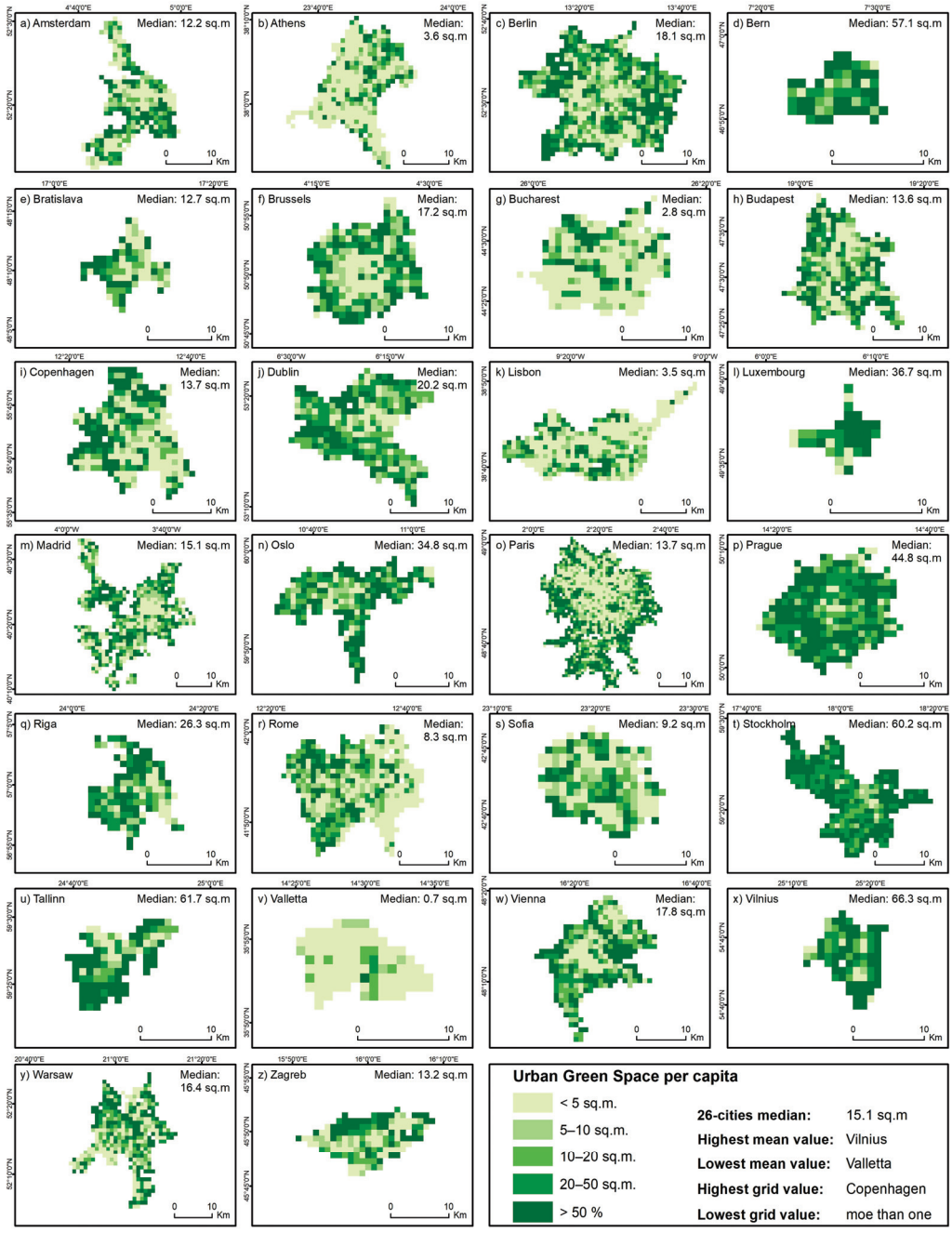

Figure 4. UGS per capita per city.

In terms of mean access time to UGS, the results show that in several cities, the majority of the population has access within less than 5 min, especially in cities with dense and evenly distributed green spaces such as Stockholm, Prague, and Vilnius (Figure 5). In contrast, the highest mean access times are found in Valletta (9.2 min), Bucharest (7.9 min), Lisbon (7.8 min), and Rome (7.6 min), indicating greater distances between residents and the nearest UGS. The maps reveal that cities with high access values often exhibit patterns of regional isolation, with areas on the outskirts of urban centers being at a significant disadvantage in terms of proximity to green spaces. This phenomenon is more pronounced in cities with a dense central built-up area and a sparser presence of UGS on the outskirts, such as Rome, Vienna, and Athens.

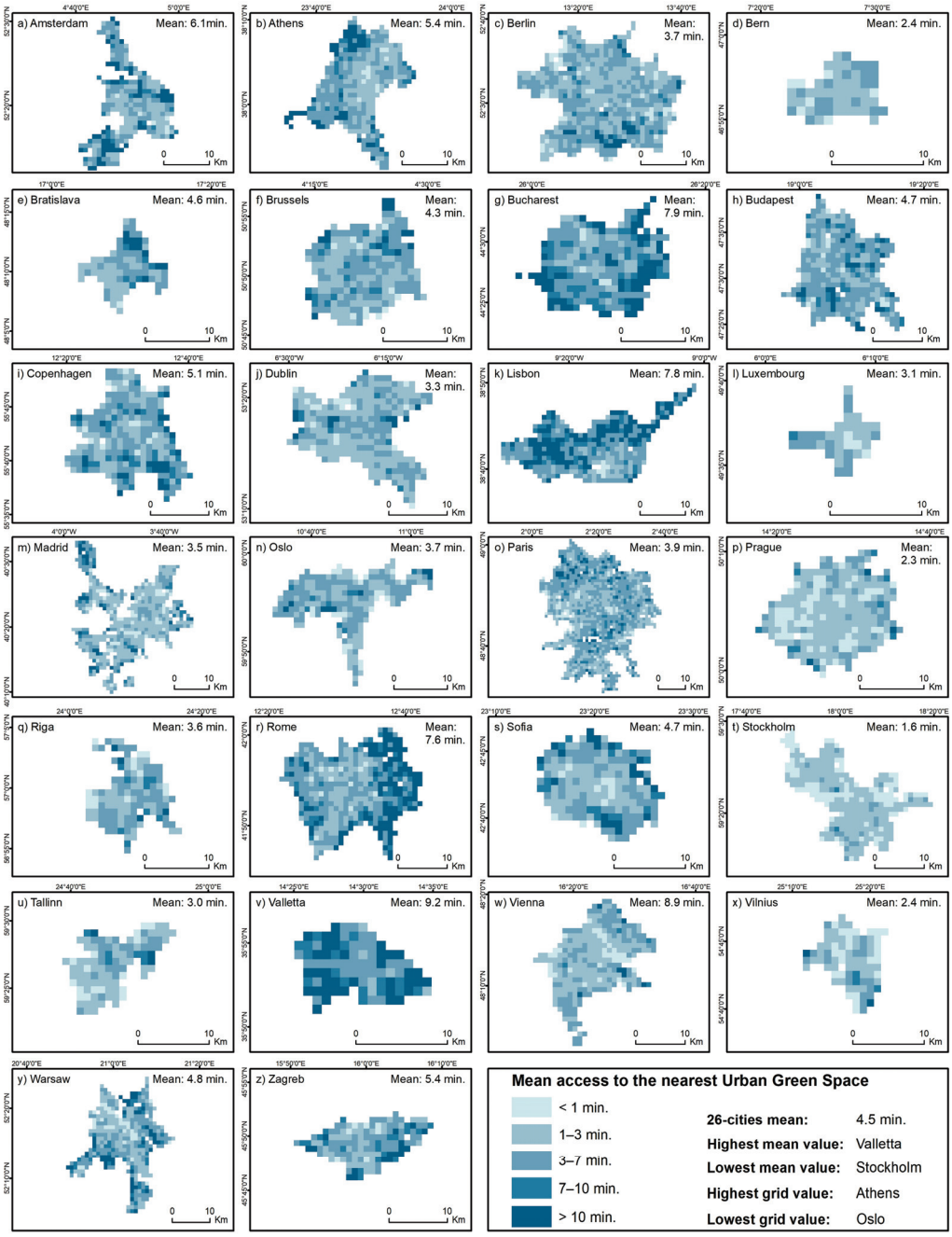

Figure 5. Mean access to the nearest UGS per city.

While the mean access time provides a general overview for each population grid polygon, it fails to reflect potential intra-grid variability, which may lead to the calculation of deceptively low mean times. In several cases, residents of the same area may be significantly closer to or further away from the nearest UGS, highlighting the need for further investigation of intra-spatial differentiation.

The range of access time per grid provides indications of internal homogeneity or inequality of access to green spaces. In several cities, there are grids where residents have almost equal access (low range), which is mainly found in Northern European cities (Figure 6). In contrast, in cities such as Rome, Valletta, Bucharest, and Lisbon, there are extensive areas with a high range of access time, revealing intense intra-spatial differentiation even on a small scale.

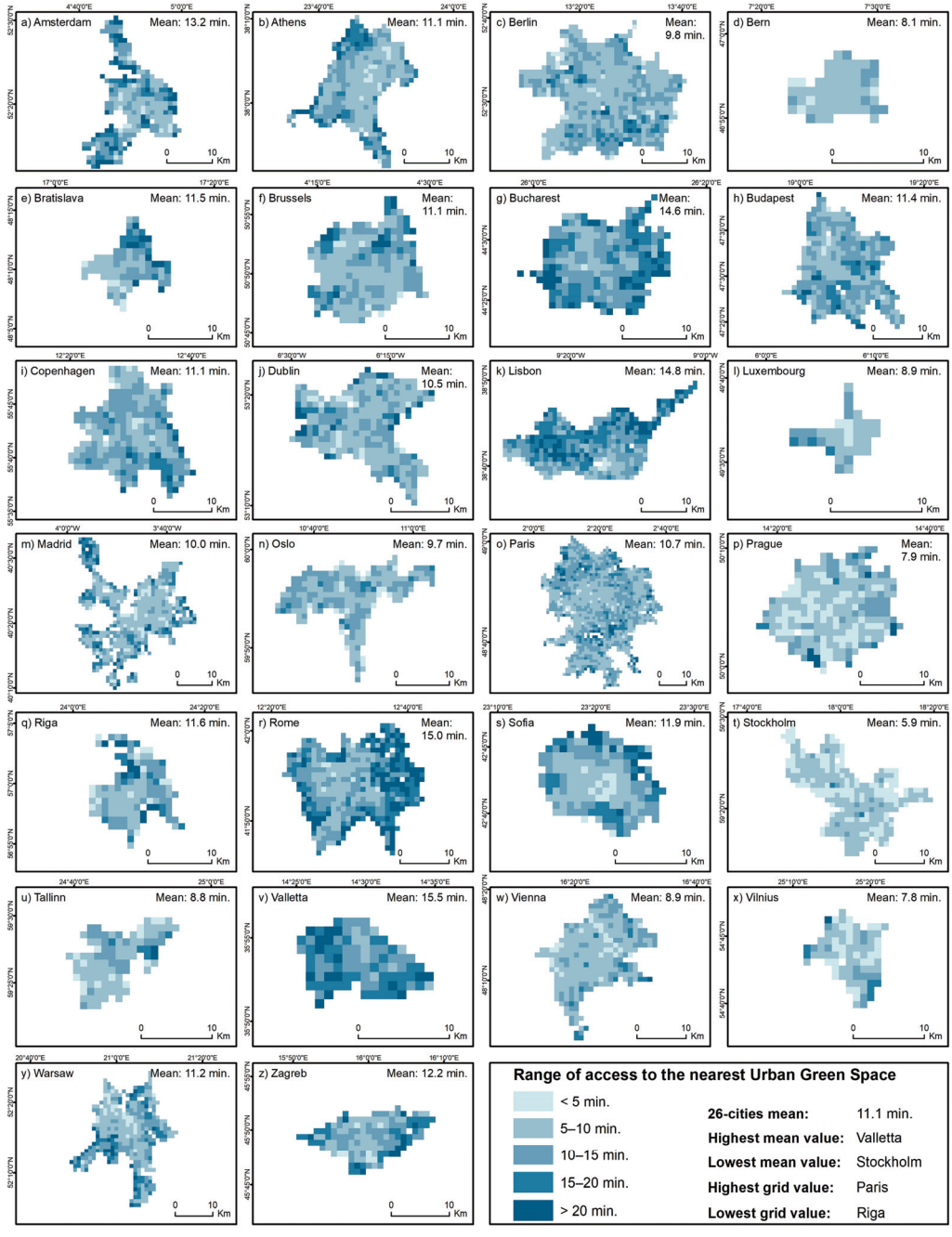

Figure 6. Range of access to the nearest UGS per city.

The maps of the need pillar variables highlight the population patterns of European capitals, focusing on population density and the presence of vulnerable age groups. The average population density for all 26 cities is 5598 residents/sq.km., but the differences between cities are significant and often extensive (Figure 7). Cities such as Paris, Madrid, and Athens, with values in areas exceeding 15,000 residents/sq.km., have average densities 40–80% higher than the overall average, indicating particularly densely populated urban areas. In contrast, in some cities, such as Bern, Luxembourg, and Valletta, values are at least 30% below the average, reflecting more diffuse or sparse settlement patterns within urban centers. The majority of cities fall within a range of ±25% of the average value, revealing the existence of some strong upward or downward deviations that affect the overall distribution. Figure 7 illustrates these differences, as in many cities the built-up center has a high population concentration compared to the peripheral areas, which are characterized by sparser settlement and lower built-up density.

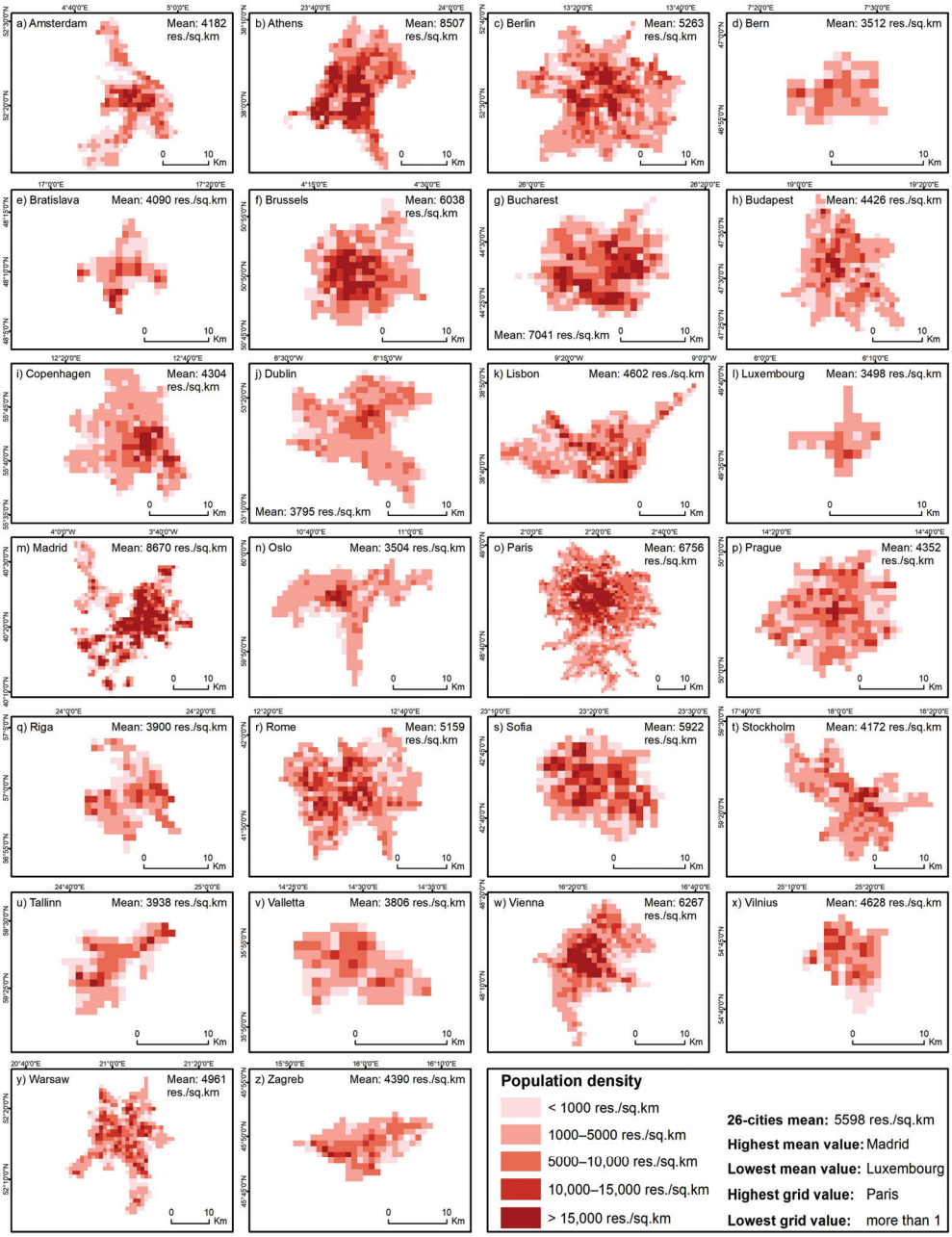

Figure 7. Population density per city.

While population density shows local concentrations of high intensity, particularly in the central parts of several cities, the spatial distribution of age groups appears more stable and less polarized compared to variables related to urban greenery (Figures 8 and 9). The mean percentage of children under 15 for all cities is 16.3%, with the highest mean values observed in Paris (19.8%), Brussels (19%), Stockholm (18.6%), and Oslo (9.7%) (Figure 8). In contrast, lower percentages of children are found in Valletta (13.2%), Rome (13.5%), Budapest (13.6%), and Berlin (13.9%), cities with a relatively older population profile. For the elderly (65+ years) group, most urban centers range between 16–22%, with slightly higher mean values in Berlin (21.9%), Rome (21.7%), and Lisbon (21.2%), which have higher proportions of elderly people in the urban population compared to other cities (Figure 9). Although there are no extreme spatial concentrations in the age groups, there are local variations within cities. Higher percentages of children are found in peripheral areas of cities such as Bucharest, Prague, Madrid, and Warsaw, while older people appear to be more concentrated in areas of lower density or more sparsely built, such as areas of Amsterdam, Bern, and Lisbon.

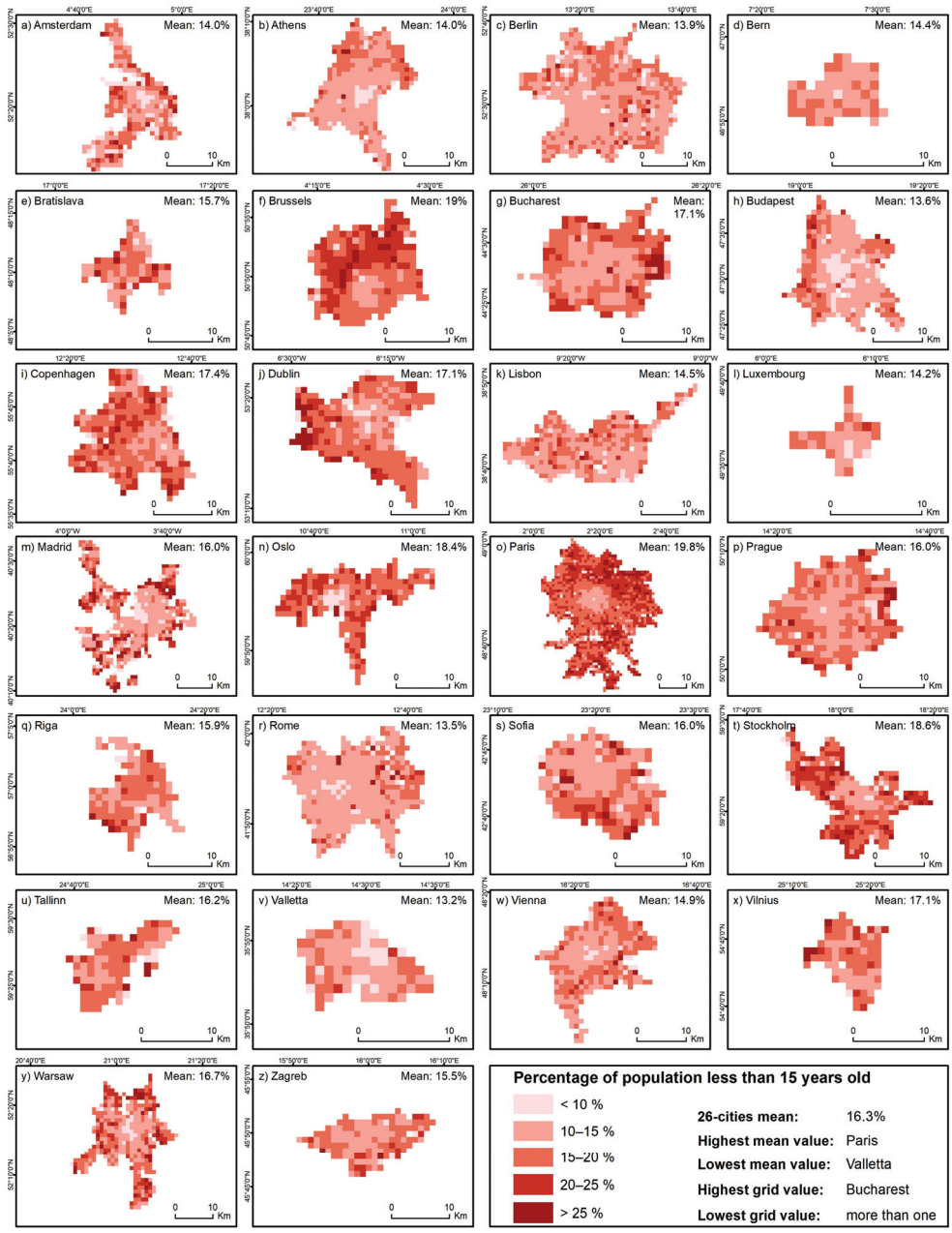

Figure 8. Percentage of population less than 15 years old per city.

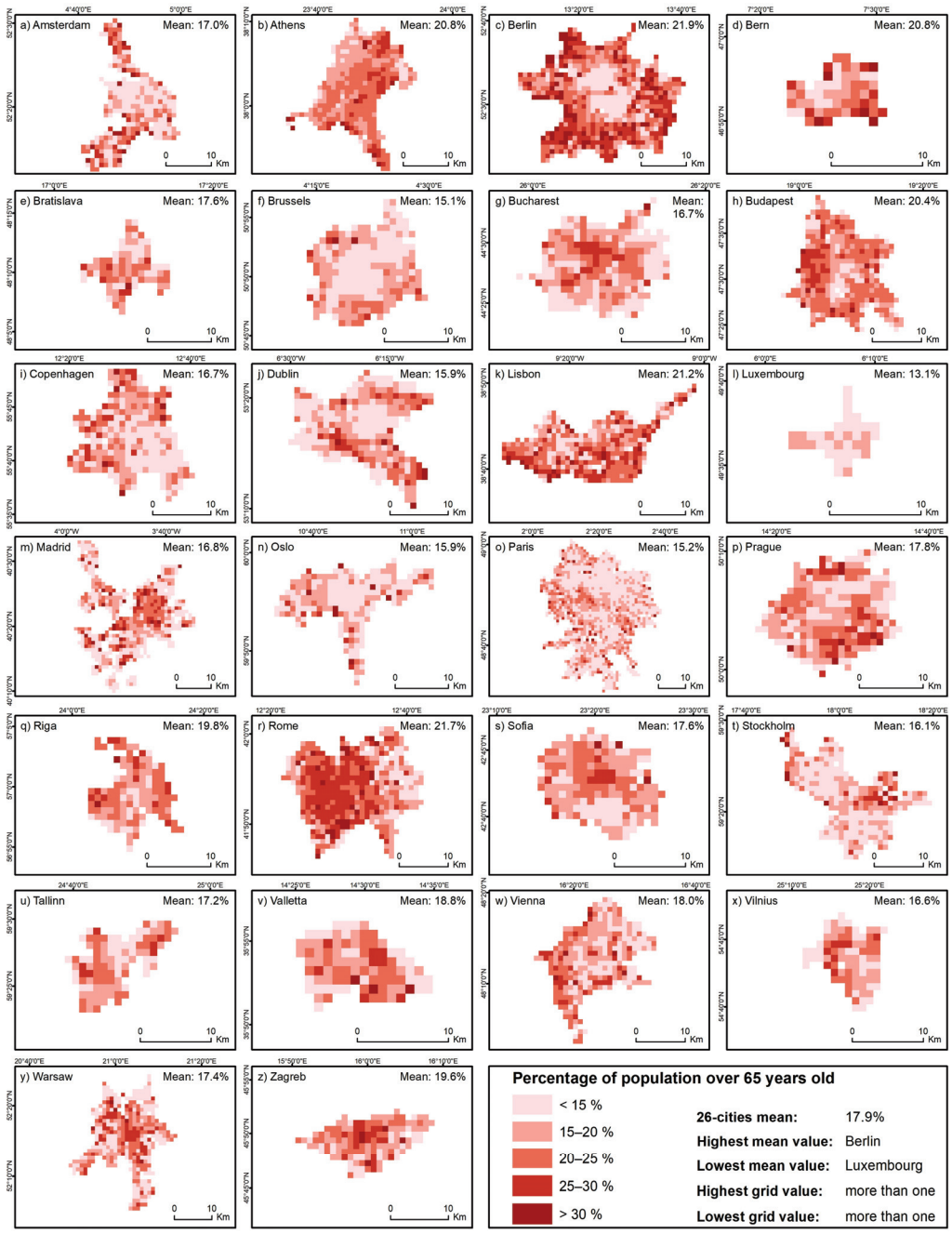

Figure 9. Percentage of population higher than 65 years old per city.

The composite UGEI, as shown in Figure 10, summarizes the three dimensions of equity in urban greenery: availability, accessibility, and need. The average value of the index for European cities is 0.423, with most Northern European cities above the average and most Southern cities below it. Higher average values are observed in Stockholm (0.473), Vilnius (0.456), Prague (0.451), Bern (0.448), and Oslo and Tallinn (0.446). These cities have larger contiguous areas with relatively high levels of equity, which indicates both high availability and accessibility of UGS in areas with increased social need. In contrast, lower values of the index are recorded in Valletta (0.373), Rome (0.383), Lisbon (0.387), Bucharest (0.388), and Athens (0.399). These cities are characterized by marked spatial inequality, with large areas having low index values and urban green spaces often being fragmented, limited, or poorly accessible.

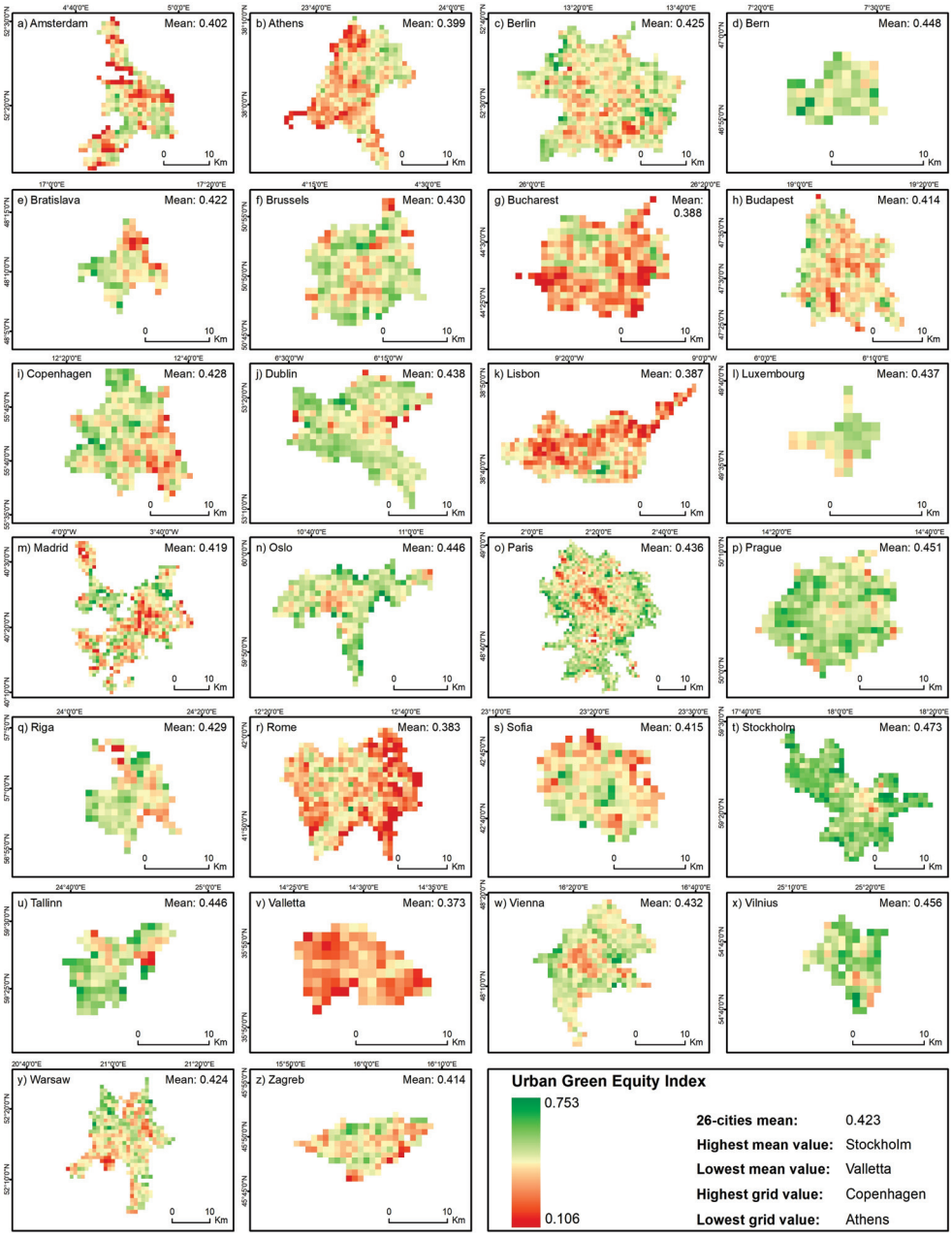

Figure 10. Urban Green Equity Index per city.

4. Discussion

This study approaches spatial justice in UGS through the development and application of the composite index UGEI in 26 European capitals, seeking to quantify the multidimensional concept of environmental equity based on three fundamental axes: availability, accessibility, and social need.

The choice of a multifactorial tool is in line with the current methodological shift towards incorporating more than one index to capture the relationship between population and green infrastructure, as the use of one-dimensional measurements has proven insufficient for understanding environmental (in)equality in urban areas [36]. The design of the UGEI is consistent with other composite indices evaluating UGS inequalities, according to which equitable access to urban green space should be assessed through the triad of availability, physical accessibility, and social need [17–20]. The incorporation of demographic parameters, such as age composition (children, elderly), reflects the importance of a "need-driven" approach to green network design [9,29], as has been argued in

studies linking access to green spaces with public health and environmental sustainability indicators [20,37,38]. This emphasis on demographic vulnerability is reflected in the structure of the need component, as the PCA showed that the proportions of younger and elderly residents were the variables most strongly associated with this axis, whereas population density contributed only weakly.

The analysis in this study reveals marked inequalities in the availability, access, and sociodemographic distribution of UGS, both at the transnational and intra-urban levels, confirming and reinforcing findings from international research on the unequal geographical and sociodemographic distribution of environmental goods in cities. Recent studies on urban greening also highlight that such disparities persist in European and global cities, demonstrating that such inequalities constitute a persistent and geographically widespread feature of contemporary urban environments [39–41].

The spatial pattern of UGEI appears to result from the interaction of all parameters, which makes even the most complex forms of urban inequality visible. This observation is consistent with studies indicating that a quantitative increase in urban greenery does not automatically imply social justice [8,11,42,43].

The spatial comparison indicates a clear geographical trend, with northern and Scandinavian cities scoring higher overall, in contrast to southern and Mediterranean cities, which score lower on the UGEI index. Cities in southern Europe have lower levels of both availability and accessibility to urban green spaces, while in many cases there are large disparities even within the same urban area.

This trend is consistent with recent findings in the international literature, which report a systematic distinction between cities in Northern and Southern Europe regarding UGS. Studies investigating UGS in European cities [44–46] document that in cities in Mediterranean countries, green spaces are often concentrated in a few large hubs or peripheral areas, while they are often characterized by lower green space indicators, higher building density, and greater intra-urban variations. In contrast, cities in Northern Europe tend to have more polycentric urban green networks, with strong neighborhood-level connectivity and greater proximity to daily travel [44,47].

Similarly, recent findings by the European Environment Agency [29] confirm that cities in Northern and Western Europe tend to have more total green space compared to cities in Southern and Eastern Europe, while socially vulnerable groups often lack access to quality UGS, even in cities with relatively high levels of overall coverage. The results of the present study consistently follow the above patterns, indicating that geographical location remains a determining factor in spatial inequalities in urban green space.

The poor performance of cities such as Athens, Rome, and Bucharest in terms of the availability and accessibility of urban green space is attributed to historical patterns of unregulated and unplanned urbanization, where priority was given to building development over the protection of public space. The lack of coherent urban planning, the deregulation of spatial planning, and the absence of an institutional framework for green spaces have led to the degradation of environmental infrastructure over time.

On the contrary, cities such as Stockholm and Tallinn confirm that urban planning strategies focused on equal access to green spaces, such as the regional planning of green infrastructure in Sweden or the "green corridors" policy in Estonia, significantly enhance social and environmental cohesion. Recent research shows that green planning at the local level, when it incorporates social and demographic criteria, contributes significantly to reducing environmental inequalities [7,48].

However, even in cities with high overall levels of green space, recent research has shown that intra-urban variations may still exist. Studies examining cities in northern Europe, such as Copenhagen, Oslo, and Riga, have identified spatial differences in the

distribution and accessibility of green spaces, with some areas showing lower availability or poorer exposure conditions than more privileged neighborhoods [15,49,50]. These findings are consistent with the results of the present study, according to which high overall UGEI values at the city level do not necessarily imply the elimination of local inequalities in the urban fabric. Based on the literature, UGS are often concentrated in areas with low population density and higher socioeconomic characteristics, leaving vulnerable neighborhoods without adequate access [30]. Recent work has shown that socially disadvantaged communities consistently experience poorer access to high-quality green spaces, even within green-rich cities [12,51]. The need for targeted interventions in socially vulnerable areas is therefore particularly urgent.

However, the study has certain limitations that must be acknowledged in order to interpret the findings correctly. First, the analysis is based on land use data (Urban Atlas 2018) and 1 × 1 km polygon-based grid data, which offer unified coverage and comparability but may not capture small-scale variations, especially in densely populated areas with intense micro-spatial complexity. Furthermore, the use of the road network access time calculation method assumes homogeneous pedestrian mobility and does not take into account obstacles such as steep slopes, high crime areas, or socially "invisible" boundaries, which affect the actual use of green spaces. In addition, the use of a uniform average walking speed (4.8 km/h) may not fully reflect the differences between age groups or groups with different mobility levels. Although this value is widely used in international literature for walkability and accessibility studies, the lack of available, harmonized data for different population categories, as well as the absence of information on mobility conditions and related pedestrian infrastructure for people with limited mobility, does not allow for the application of distinct speeds in a comparative analysis between cities.

Furthermore, the analysis focuses on pedestrian access to static points (nearest UGS) rather than on the overall quality or functionality of green spaces, which also determine their use and importance. These qualities, such as safety, equipment, esthetics, biodiversity, or cultural content, could not be incorporated into the index due to a lack of harmonized data at the European level, even though the literature recognizes them as determining factors for the sustainability of UGS [20].

Another important assumption of the study is the equation of social need with age composition and population density. Although these parameters are widely accepted indicators of vulnerability, they do not cover other critical social variables, such as income, ethnic composition, or the existence of disabilities, which are often associated with reduced access to green spaces [29,52]. The inclusion of such parameters would enhance the social robustness of the index and provide a more comprehensive understanding of urban inequality.

Finally, there is a temporal inconsistency between the datasets used in the analysis, as they come from different European data providers and correspond to the most recent versions available for each type of data. Although this implies a small time gap, ranging up to approximately seven years (2018–2025), the complete temporal alignment of all variables at the European scale is challenging to achieve. However, given that green spaces and road networks usually remain relatively stable over such short time periods in urban environments, these temporal discrepancies are not expected to substantially affect the overall spatial patterns or the comparative results of the analysis.

Despite the limitations, this study contributes to the empirical and comparative documentation of inequalities in urban greenery in Europe, offering a valuable pan-European picture of green urban justice at the level of capital cities. The development of the composite UGEI allows for the simultaneous capture of availability, accessibility, and need, offering

a more holistic understanding of environmental equity compared to one-dimensional indices that focus exclusively on green coverage or proximity.

Furthermore, the use of spatially high-resolution data (1×1 km) and the incorporation of social vulnerability parameters, such as age composition and density, enhance the ability to target areas with an increased need for green interventions.

The application of a uniform methodology to geographically and institutionally diverse cities provides a powerful tool for comparative assessment, which is particularly useful for both urban policymakers and the scientific community examining issues of environmental justice and sustainable urban planning. This study advances beyond existing literature by offering a comparative, empirically grounded, and integrated assessment of green equity in European capitals. The combined analysis of the three dimensions of the UGEI, availability, accessibility, and social need, allows for the identification of complex spatial patterns that often remain invisible in one-dimensional approaches. Beyond its contribution to the scientific documentation of inequalities, the study provides operational guidance for policy-making.

The study's findings are particularly relevant for urban policy. The systematic measurement of the three dimensions of green justice makes the UGEI a useful tool for identifying priorities and documenting targeted interventions. Based on the data collected and analyzed, certain operational guidelines for policy-making emerge: (a) prioritizing areas with low accessibility or high social vulnerability for increasing green space, (b) incorporating socioeconomic and demographic indicators into the spatial planning process, and (c) using the UGEI indicator as a tool for monitoring and evaluating progress towards more equitable and sustainable cities. This systematic approach can support policymakers and city administrations in developing evidence-based green transition strategies in the European context.

Overall, this study highlights the importance of a holistic, socially sensitive, and quantitatively grounded approach to urban greenery assessment, in line with the new generation of research shifting from general surface area measurement to multifactorial environmental justice assessment.

5. Conclusions

The conclusions of this study are based directly on the patterns identified through the spatial results of the UGEI analysis. The mapping results indicated consistent geographical variations and intra-urban inequalities, which form the empirical basis for the study's broader findings on environmental inequalities. In summary, the study highlighted the multidimensional inequalities of availability, accessibility, and population need for UGS in 26 European capitals, confirming, within the European context, that the quantitative increase in green space does not automatically ensure environmental justice. The composite UGEI allowed a more holistic approach to the phenomenon, providing the possibility for comparative assessment and identification of areas of high need, while underlining the value of integrating social and demographic variables into urban planning.

However, to further deepen the understanding of green inequality, future research could incorporate additional socioeconomic indicators, such as income, ethnic composition, education level, or housing conditions, as well as qualitative characteristics of green spaces (e.g., safety, esthetics, maintenance). Future developments of the index could also integrate functional or ecological attributes through remotely sensed indicators, such as vegetation indices (e.g., NDVI) or tree canopy cover, along with survey-based data on user experience and perceptions at the city level. Such extensions would allow a more comprehensive assessment of urban green space equity, linking spatial accessibility with the quality and usability of green areas. Furthermore, the use of longitudinal data and the study of the

impacts of green interventions could contribute to the understanding of processes of environmental (in)equality and the dynamics of "green gentrification". In this context, temporal analyses based on successive Urban Atlas releases or other comparable datasets could deepen knowledge of how green space equity evolves over time in European cities.

These research directions could expand the empirical framework developed in this paper and enhance understanding of how spatial and social structures influence green equity in European cities. Finally, the strengthening of participatory processes in the planning and evaluation of urban green spaces can be a crucial step towards creating cities that are not only sustainable but also more socially just.

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Data Availability Statement: The original data presented in the study are openly available in Global Human Settlement Database—Urban Centre Database (GHS-UCDB) at https://human-settlement.emergency.copernicus.eu/ghs_ucdb_2024.php (accessed on 10 July 2025), EEA geospatial data at https://doi.org/10.2909/fb4dffa1-6ceb-4cc0-8372-1ed354c285e6, and Eurostat at https://ec.europa.eu/eurostat/web/gisco/geodata/population-distribution/population-grids (accessed on 10 July 2025).

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EEA	European Environment Agency
EPSG	European Petroleum Survey Group
ETRS89	European Terrestrial Reference System 1989
GHS-UCDB	Global Human Settlement Database—Urban Centre Database
GIS	Geographical Information Systems
GISCO	Geographic Information System of the Commission
JRC	Joint Research Centre
LAEA	Lambert Azimuthal Equal Area
OSM	OpenStreetMap
PCA	Principal Component Analysis
sq.m.	square meters
sq.km.	square kilometers
UGS	Urban Green Spaces
UGEI	Urban Green Equity Index
VIF	Variance Inflation Factor
WHO	World Health Organization

References

1. Nieuwenhuijsen, M.J. Green Infrastructure and Health. *Annu. Rev. Public Health* **2020**, *42*, 317–328. [CrossRef]
2. WHO. *Urban Green Spaces and Health: A Review of Evidence*; WHO Regional Office for Europe: Copenhagen, Denmark, 2016.
3. Kabisch, N.; Qureshi, S.; Haase, D. Human–environment interactions in urban green spaces—A systematic review of contemporary issues and prospects for future research. *Environ. Impact Assess. Rev.* **2015**, *50*, 25–34. [CrossRef]
4. Haase, D.; Kabisch, S.; Haase, A.; Andersson, E.; Banzhaf, E.; Baró, F.; Brenck, M.; Fischer, L.K.; Frantzeskaki, N.; Kabisch, N.; et al. Greening cities—To be socially inclusive? About the alleged paradox of society and ecology in cities. *Habitat Int.* **2017**, *64*, 41–48. [CrossRef]
5. van den Bosch, M.; Ode Sang, Å. Urban natural environments as nature-based solutions for improved public health—A systematic review of reviews. *Environ. Res.* **2017**, *158*, 373–384. [CrossRef]
6. Anguelovski, I.; Connolly, J.J.T.; Masip, L.; Pearsall, H. Assessing green gentrification in historically disenfranchised neighborhoods: A longitudinal and spatial analysis of Barcelona. *Urban Geogr.* **2018**, *39*, 458–491. [CrossRef]

7. Kifayatullah, S.; Saqib, Z.; Khan, M.I.; Zaman-ul-Haq, M.; Kucher, D.E.; Ullah, S.; Tariq, A. Equitable urban green space planning for sustainable cities: A GIS-based analysis of spatial disparities and functional strategies. *Sci. Rep.* **2025**, *15*, 22686. [CrossRef] [PubMed]
8. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landsc. Urban Plan.* **2014**, *125*, 234–244. [CrossRef]
9. Rigolon, A. A complex landscape of inequity in access to urban parks: A literature review. *Landsc. Urban Plan.* **2016**, *153*, 160–169. [CrossRef]
10. Li, M.; Chen, T.; Li, J.; Yang, G.; Zhao, L.; Cao, Q.; Yang, L.; Sun, Y. Advancing sustainability in urban planning by measuring and matching the supply and demand of urban green space ecosystem services. *Sustainability* **2024**, *16*, 10306. [CrossRef]
11. Kabisch, N.; Haase, D. Green justice or just green? Provision of urban green spaces in Berlin, Germany. *Landsc. Urban Plan.* **2014**, *122*, 129–139. [CrossRef]
12. Chen, Y.; Yue, W.; La Rosa, D. Which communities have better accessibility to green space? An investigation into environmental inequality using big data. *Landsc. Urban Plan.* **2020**, *204*, 103919. [CrossRef]
13. Guo, S.; Song, C.; Pei, T.; Liu, Y.; Ma, T.; Du, Y.; Chen, J.; Fan, Z.; Tang, X.; Peng, Y.; et al. Accessibility to urban parks for elderly residents: Perspectives from mobile phone data. *Landsc. Urban Plan.* **2019**, *191*, 103642. [CrossRef]
14. Yan, L.; Jin, X.; Zhang, J. Equity in park green spaces: A bibliometric analysis and systematic literature review from 2014–2023. *Front. Environ. Sci.* **2024**, *12*, 1374973. [CrossRef]
15. Venter, Z.S.; Figari, H.; Krange, O.; Gundersen, V. Environmental justice in a very green city: Spatial inequality in exposure to urban nature, air pollution and heat in Oslo, Norway. *Sci. Total Environ.* **2023**, *858*, 160193. [CrossRef]
16. Vaňo, S.; Stahl Olafsson, A.; Mederly, P. Advancing urban green infrastructure through participatory integrated planning: A case from Slovakia. *Urban For. Urban Green.* **2021**, *58*, 126957. [CrossRef]
17. Annerstedt Van Den Bosch, M.; Mudu, P.; Uscila, V.; Barrdahl, M.; Kulinkina, A.; Staatsen, B.; Swart, W.; Kruize, H.; Zurlyte, I.; Egorov, A.I. Development of an urban green space indicator and the public health rationale. *Scand. J. Public Health* **2016**, *44*, 159–167. [CrossRef] [PubMed]
18. Campagnaro, T.; Sitzia, T.; Cambria, V.E.; Semenzato, P. Indicators for the planning and management of urban green spaces: A focus on public areas in Padua, Italy. *Sustainability* **2019**, *11*, 7071. [CrossRef]
19. Kuklina, V.; Sizov, O.; Fedorov, R. Green spaces as an indicator of urban sustainability in the Arctic cities: Case of Nadym. *Polar Sci.* **2021**, *29*, 100672. [CrossRef]
20. Nesbitt, L.; Meitner, M.J.; Girling, C.; Sheppard, S.R.J. Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landsc. Urban Plan.* **2019**, *181*, 51–79. [CrossRef]
21. Adorno, B.V.; Pereira, R.H.M.; Amaral, S. Combining spatial clustering and spatial regression models to understand distributional inequities in access to urban green spaces. *Landsc. Urban Plan.* **2025**, *256*, 105297. [CrossRef]
22. Hsu, Y.-Y.; Hawken, S.; Sepasgozar, S.; Lin, Z.-H. Beyond the Backyard: GIS Analysis of Public Green Space Accessibility in Australian Metropolitan Areas. *Sustainability* **2022**, *14*, 4694. [CrossRef]
23. Kmail, A.B.; Onyango, V. A GIS-based assessment of green space accessibility: Case study of Dundee. *Appl. Geomat.* **2020**, *12*, 491–499. [CrossRef]
24. Vîlcea, C.; Șoșea, C. A GIS-based analysis of the urban green space accessibility in Craiova city, Romania. *Geogr. Tidsskr. Dan. J. Geogr.* **2020**, *120*, 19–34. [CrossRef]
25. Kolcsár, R.A.; Csete, Á.K.; Kovács-Győri, A.; Szilassi, P. Age-group-based evaluation of residents' urban green space provision: Szeged, Hungary. A case study. *Hung. Geogr. Bull.* **2022**, *71*, 249–269. [CrossRef]
26. Mumm, O.; Zeringue, R.; Dong, N.; Carlow, V.M. Green Densities: Accessible Green Spaces in Highly Dense Urban Regions—A Comparison of Berlin and Qingdao. *Sustainability* **2022**, *14*, 1690. [CrossRef]
27. Csomós, G.; Farkas, J.Z.; Kovács, Z. A GIS-based assessment of different income groups' access to multiple types of green areas in Budapest, Hungary. *Habitat Int.* **2024**, *146*, 103054. [CrossRef]
28. European Commission. *EU Biodiversity Strategy for 2030: Bringing Nature Back into Our Lives*; Publications Office of the European Union: Luxembourg, 2021.
29. European Environment Agency. *Who Benefits from Nature in Cities?* EEA: Copenhagen, Denmark, 2022. Available online: https://www.eea.europa.eu/publications/who-benefits-from-nature-in (accessed on 10 July 2025).
30. Buckland, M.; Pojani, D. Green space accessibility in Europe: A comparative study of five major cities. *Eur. Plan. Stud.* **2023**, *31*, 146–167. [CrossRef]
31. Marí Rivero, I.; Melchiorri, M.; Florio, P.; Schiavina, M.; Krasnodębska, K.; Politis, P.; Uhl, J.; Pesaresi, M.; Maffenini, L.; Sulis, P.; et al. *GHS Urban Centre Database 2024, Multitemporal and Multidimensional Attributes, R2024A*; European Commission, Joint Research Centre (JRC): Luxembourg, 2024.
32. Copernicus Land Monitoring Service; European Environment Agency. *Urban Atlas Land Cover/Land Use 2018 (Vector)*; Europe, Edition 01.03, Revision 03; European Environment Agency: Copenhagen, Denmark, 2020. [CrossRef]

33. Eurostat. Population Grids—GISCO. 2021. Available online: https://ec.europa.eu/eurostat/web/gisco/geodata/population-distribution/population-grids (accessed on 10 July 2025).
34. Karamitov, K.; Petrova-Antonova, D. Pedestrian accessibility assessment using spatial and network analysis: A case of Sofia city. *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.* **2022**, *XLVIII-4/W5-2022*, 53–60. [CrossRef]
35. Tennøy, A.; Knapskog, M.; Wolday, F. Walking distances to public transport in smaller and larger Norwegian cities. *Transp. Res. D Transp. Environ.* **2022**, *103*, 103169. [CrossRef]
36. Battiston, A.; Schifanella, R. On the need for a multi-dimensional framework to measure accessibility to urban green. *npj Urban Sustain.* **2024**, *4*, 10. [CrossRef]
37. Banwell, N.; Michel, S.; Senn, N. Greenspaces and health: Scoping review of studies in Europe. *Public Health Rev.* **2024**, *45*, 1606863. [CrossRef] [PubMed]
38. Jennings, V.; Johnson Gaither, C.; Gragg, R.S. Promoting environmental justice through urban green space access: A synopsis. *Environ. Justice* **2012**, *5*, 1–7. [CrossRef]
39. Asadi, M.; Nastaran, M. Investigating equitable access of children and seniors to urban green spaces and its relationship with neighborhood walkability: A case study of Tehran, Iran. *Cities Health* **2024**, *8*, 1053–1063. [CrossRef]
40. Anguelovski, I.; Connolly, J.J.T.; Cole, H.; Garcia-Lamarca, M.; Triguero-Mas, M.; Baró, F.; Martin, N.; Conesa, D.; Shokry, G.; del Pulgar, C.P.; et al. Green gentrification in European and North American cities. *Nat. Commun.* **2022**, *13*, 3816. [CrossRef]
41. Xie, Q.; Lu, M. Measures of spatial and demographic disparities in access to urban green space in harbin, China. *Complexity* **2020**, *2020*, 8832343. [CrossRef]
42. Zhu, C.; Zheng, S.; Yang, S.; Yao, Y.; Han, B. Towards a green equal city: Measuring and matching the supply-demand of green exposure in urban center. *J. Environ. Manag.* **2024**, *365*, 121510. [CrossRef]
43. Nicoletti, L.; Sirenko, M.; Verma, T. Disadvantaged communities have lower access to urban infrastructure. *Environ. Plan. B Urban Anal. City Sci.* **2023**, *50*, 831–849. [CrossRef]
44. Łaszkiewicz, E.; Wolff, M.; Andersson, E.; Kronenberg, J.; Barton, D.N.; Haase, D.; Langemeyer, J.; Baró, F.; McPhearson, T. Greenery in urban morphology: A comparative analysis of differences in urban green space accessibility for various urban structures across European cities. *Ecol. Soc.* **2022**, *27*, 22. [CrossRef]
45. Pristeri, G.; Peroni, F.; Pappalardo, S.E.; Codato, D.; Masi, A.; De Marchi, M. Whose urban green? Mapping and classifying public and private green spaces in padua for spatial planning policies. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 538. [CrossRef]
46. Sdoukopoulos, A. A Methodological Approach for Estimating Urban Green Space: The Case of Thessaloniki, Greece. *Adv. Intell. Syst. Comput.* **2021**, *1278*, 728–738.
47. Stessens, P.; Canters, F.; Huysmans, M.; Khan, A.Z. Urban green space qualities: An integrated approach towards GIS-based assessment reflecting user perception. *Land Use Policy* **2020**, *91*, 104319. [CrossRef]
48. Haaland, C.; van den Bosch, C.K. Challenges and strategies for urban green-space planning in cities undergoing densification: A review. *Urban For. Urban Green.* **2015**, *14*, 760–771. [CrossRef]
49. Ribeiro, G.; Nowak, A. Age Distribution and Accessibility to Green Areas in the City of Copenhagen. In *Design for Health*; Hasan, A., Benimana, C., Ramsgaard Thomsen, M., Tamke, M., Eds.; Sustainable Development Goals Series; UIA 2023; Part F2788; Springer: Cham, Switzerland, 2023; pp. 57–76.
50. Sechi, G.; Bērziņš, M.; Krišjāne, Z. Environmental Justice in the Post-socialist City. The Case of Riga, Latvia. In *Whose Green City?* Plüschke-Altof, B., Sooväli-Sepping, H., Eds.; Sustainable Development Goals Series; Part F2733; Springer: Cham, Switzerland, 2022; pp. 59–79.
51. Plüschke-Altof, B.; Sooväli-Sepping, H. Contested Urban Green Spaces and Environmental Justice in Northern Europe. In *Whose Green City?* Plüschke-Altof, B., Sooväli-Sepping, H., Eds.; Sustainable Development Goals Series; Part F2733; Springer: Cham, Switzerland, 2022; pp. 1–16.
52. Yang, J.; Chen, M. Assessing the impact of urban amenities on people with disabilities in London: A multiscale geographically weighted regression analysis. *Habitat Int.* **2025**, *161*, 103426. [CrossRef]

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Spatial–Temporal Characteristics and Influencing Factors of Shrinking County Towns' Resilience in China

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Abstract: Enhancing shrinking county towns' resilience (SCTR) is crucial for fostering high-quality development and supporting China's new urbanization strategy. However, research on resilience in shrinking areas remains limited, particularly at the county level—characterized as an "urban-rural intermediary". In this study, we develop an evaluation framework based on a coupled human–environment perspective. Using this framework, we assess SCTR across various regions and levels of shrinkage in China from 2013 to 2022, while analyzing the coupling coordination degree among subsystems. To address challenges such as nonlinearity, spatial heterogeneity, and interpretability in attribution analysis, we integrate the Geographically Weighted Random Forest (GWRF) model with the SHapley Additive exPlanation (SHAP) model. The results show a gradual increase in resilience throughout the study period. Spatially, a distinct East–West disparity emerges, with higher resilience in the East and lower resilience in the West, as delineated by the Hu Line. For extreme-shrinking counties, population decline has become a paramount constraint on their resilience. Key factors, including local fiscal revenue, GDP, the Gini coefficient, and urbanization levels, have a significant impact on SCTR. Notably, in counties undergoing severe or extreme shrinkage, population decline has become a critical barrier to resilience. This study provides scientific insights and policy recommendations for the development of a sustainable and resilient county-town system in China.

Keywords: county town resilience; urban shrinkage; Geographically Weighted Random Forest; spatial–temporal evolution; critical influencing factor exploration

1. Introduction

Urban shrinkage has become a prominent field within urban development research [1–3]. This phenomenon is not limited to large cities; it is also distinctly evident in the development of small towns [4,5]. Unlike the more localized shrinkage observed in major cities [6–8], small towns tend to experience more extensive and holistic patterns of contraction [9,10]. In China, the world's largest developing country, 53% of county towns experienced population contraction between 2010 and 2020 [11], with a reduction of over 40 million working-age individuals. This population decline in county towns has emerged as a critical issue, significantly hindering the coordinated regional development of China.

County towns serve as connectors, transitional zones, and intermediaries between urban and rural areas [12]. As such, they are exposed to multiple and often overlapping pressures, including climate change, resource depletion, and land loss caused by urban expansion [13]. However, population shrinkage has exacerbated these challenges, resulting

in more complex and detrimental consequences [14,15]. This is particularly evident in population loss and the decline in economic vitality, which directly hinder the socio-economic development of rural areas [16,17]. Additionally, it gives rise to challenges such as an aging labor force, vacant housing, and surplus infrastructure [18–20]. These issues significantly undermine the flexibility, adaptability, and resilience of county towns in responding to external disruptions [21]. Therefore, systematically identifying the developmental challenges faced by shrinking county towns and exploring strategies to enhance their resilience holds considerable theoretical and practical importance.

Faced with the multiple challenges posed by urban shrinkage, traditional growth-oriented urban planning models have become increasingly unsuitable. How can county towns effectively respond to external pressures and internal dynamics while fostering sustainable development? In this context, the development of resilient county towns has become a key strategy to address population decline, mitigate disasters impacts, and promote high-quality regional development in China [22]. The concept of resilience reflects inherent attributes such as support, resistance, and the capacity for transformation [23,24]. Resilience research spans multiple scales, ranging across national [25], regional [26], city [25,27], county [12], rural [17,28], and community levels [29]. Resilience research is typically divided into two categories: (1) normalized scenarios, which evaluate resilience across economic, social, environmental, industrial, infrastructural, and policy dimensions [30,31]; and (2) risk scenarios, which examine responses to disturbances such as climate change [32], technological innovation [33], and geological hazards [34]. Theoretical resilience studies are supported by several key frameworks, including the disturbance–response framework [35,36], the socio-ecological framework [28,37,38], the adaptive cycle framework [39,40], and other classical models [41]. The convergence of resilience theory and regional development goals has emerged as a critical research frontier, underpinning efforts to foster urban systems with long-term adaptive capacity and resilience to disturbances.

Although existing studies on urban shrinkage and resilience have yielded valuable insights, limited attention has been paid to three critical aspects. First, research on the resilience of shrinking county towns remains limited. Most studies on urban shrinkage resilience and related strategies have focused on large cities [42–44]. This has led to the long-standing neglect of small towns, which play a vital role in the urban system [45–47]. County towns are a key element of China's urban network and serve as a central engine for promoting regional health and sustainable development [48]. Investigating the resilience of shrinking county towns is directly linked to the success of urban-rural integration in China, thereby influencing the broader trajectory of new-type urbanization [49]. Second, existing studies remain heavily anchored in conventional frameworks [50,51], with insufficient attention to the distinct characteristics of urban shrinkage. Urban shrinkage is not simply characterized by population loss or economic decline; it fundamentally represents a profound reconfiguration of the human–environment relationship and spatial reorganization. Therefore, adopting a human–environment system coupling perspective is crucial. This perspective helps explore the complex mechanisms underlying resilience evolution and the adaptive transformation pathways throughout the shrinkage process. Finally, existing attribution models for urban resilience often overlook spatial heterogeneity and the nonlinear effects of explanatory variables. The impact of geographic location and shrinkage severity on the resilience of county towns is inherently complex and cannot be fully captured by linear assumptions. This underscores the necessity of employing advanced and robust analytical frameworks that can account for intricate spatial dependencies and nonlinear relationships. These frameworks will allow for a more precise understanding of how various factors affect resilience during urban shrinkage.

In this context, this study adopts a coupled human–environment perspective to examine the spatiotemporal evolution of SCTR in China. The research period spans from 2013 to 2022, focusing on county towns in China. This study identifies and assesses the resilience of shrinking county towns in China. The interactions among resilience subsystems are quantified using the Coupling Coordination Degree (CCD) model. Finally, mechanisms of influencing factors on SCTR are explored through a combination of GWRF and SHAP analysis. Theoretically, our work facilitates deeper insight into SCTR, and expands the body of research on urban shrinkage and resilience. Furthermore, it will provide administrators and decision-makers with both perspectives and quantitative tools to assess policy responses in planning.

2. Materials and Methods

2.1. Study Area

This study focuses on county towns in China. The study excludes the Inner Mongolia Autonomous Region due to the lack of key statistical data for its administrative units. Regions such as Hong Kong, Macao, and Taiwan are also excluded due to data limitations. By 2022, China had 1472 county towns, including autonomous counties, banners, autonomous banners, forestry regions, and special economic zones. The lack of data for the 60 units within Inner Mongolia excludes them from the quantitative assessment. Therefore, this study focuses on the remaining 1412 county towns as the research units and identifies the shrinking towns over the study period. These shrinking towns are the primary units for assessing the SCTR. To explore the spatiotemporal dynamics of shrinkage across different regions, the study integrates seven geographical zones, as shown in Figure 1. This was done to compare the shrinkage of county towns and SCTR in different regions.

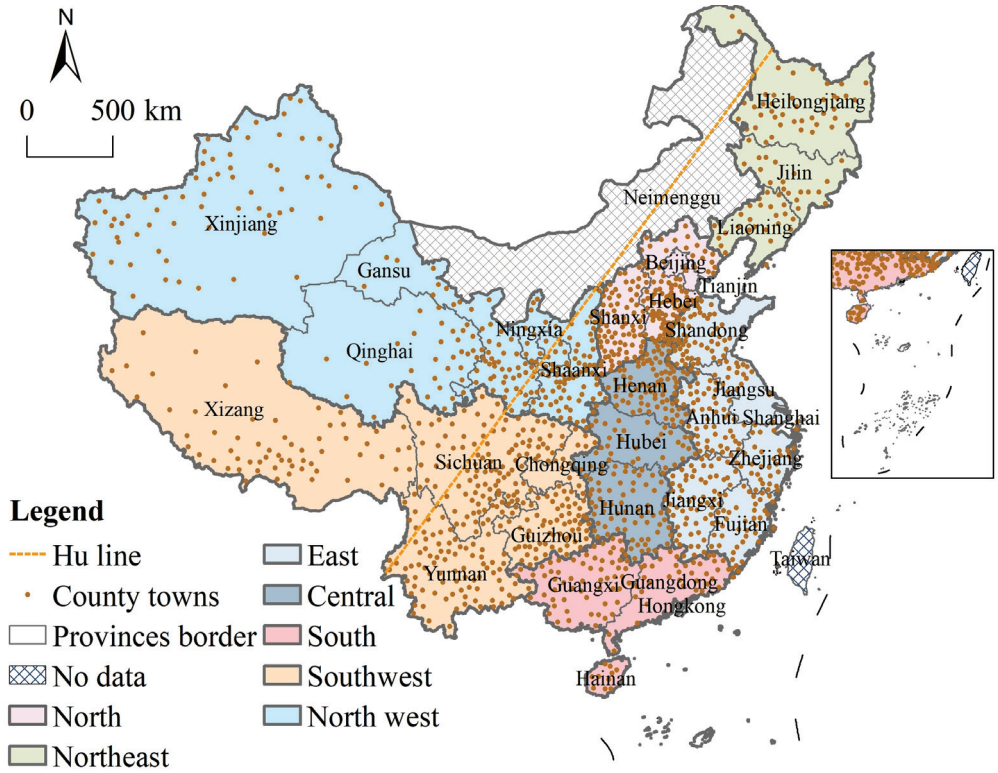

Figure 1. The spatial distribution of county towns in China and the seven geographic regions.

2.2. Data Source

The data employed in this study fall into three primary categories: the socioeconomic statistics, the natural environment data, and the GIS data. (1) Socioeconomic statistical data was obtained from statistical yearbooks of different cities and counties for 2013–2022. These data include information on population, GDP, per capita GDP, and per capita agricultural production, among others. (2) The natural environment data include DEM, NDVI, land use data, and precipitation. (3) GIS data were sourced from the National Geomatics Center of China (http://www.ngcc.cn, accessed on 5 January 2025). Given the long time span of study, 2022 county-level administrative boundaries were uniformly adopted. This ensured consistency across the research period.

To improve the accuracy of spatial analysis, remote sensing imagery, vector data, and other spatial data were standardized to the WGS 84 coordinate system and UTM projection using ArcGIS 10.5 software. Linear interpolation was utilized to impute missing data for specific years. The research data and its sources are presented in Table 1.

Table 1. Data source.

Data	Format	Source
Land use data	Raster (30 m)	Geographic Data Sharing Infrastructure, Global Resources Data Cloud (http://www.gis5g.com/, accessed on 11 January 2025)
Digital elevation model (DEM)	Raster (1 km)	Geospatial Data Cloud (https://www.gscloud.cn/, accessed on 2 January 2025)
Pm2.5 Concentration	Raster (1 km)	National Aeronautics and Space Administration (NASA)
Extreme precipitation	Raster (1 km)	National oceanic and atmosphere administration (NOAA) (https://www.ncei.noaa.gov/data/global-summary-of-the-day/archive/, accessed on 7 March 2025)
Normalized difference vegetation index (NDVI)	Raster (1 km)	National Aeronautics and Space Administration (NASA) (https://www.earthdata.nasa.gov/, accessed on 21 January 2025)

2.3. Understanding the SCTR Framework from a Coupled Human–Environment System Perspective

The coupled human–environment system has emerged as a critical theoretical framework for understanding interactions between human societies and the environment [52]. It transcends the binary opposition between anthropocentrism and environmental determinism by conceptualizing humans and the environment as a tightly integrated whole. This framework emphasizes their interdependence and mutual reinforcement [53–56]. Specifically, this system comprises three types of coupling relationships: (1) Environment-environment coupling, involving the exchange of materials and energy among natural subsystems; (2) Human–environment coupling, which supports human development activities through the provision of natural resources, typically reflected in the functional carrying capacity of urban infrastructure and spatial systems; (3) Human–human coupling, manifested in interactive feedback loops across individuals, groups, and institutions in social and economic activities. The coupled human–environment system is complex, dynamic, interconnected, and intrinsically integrated [55,57,58]. At its core, it emphasizes a dialectical relationship between humans and the environment, characterized by mutual embeddedness, tension, and synergy. Understanding these intricate dynamics is central to sustainability science [59], and essential for formulating region-specific pathways to sustainable development [60,61] (Figure 2).

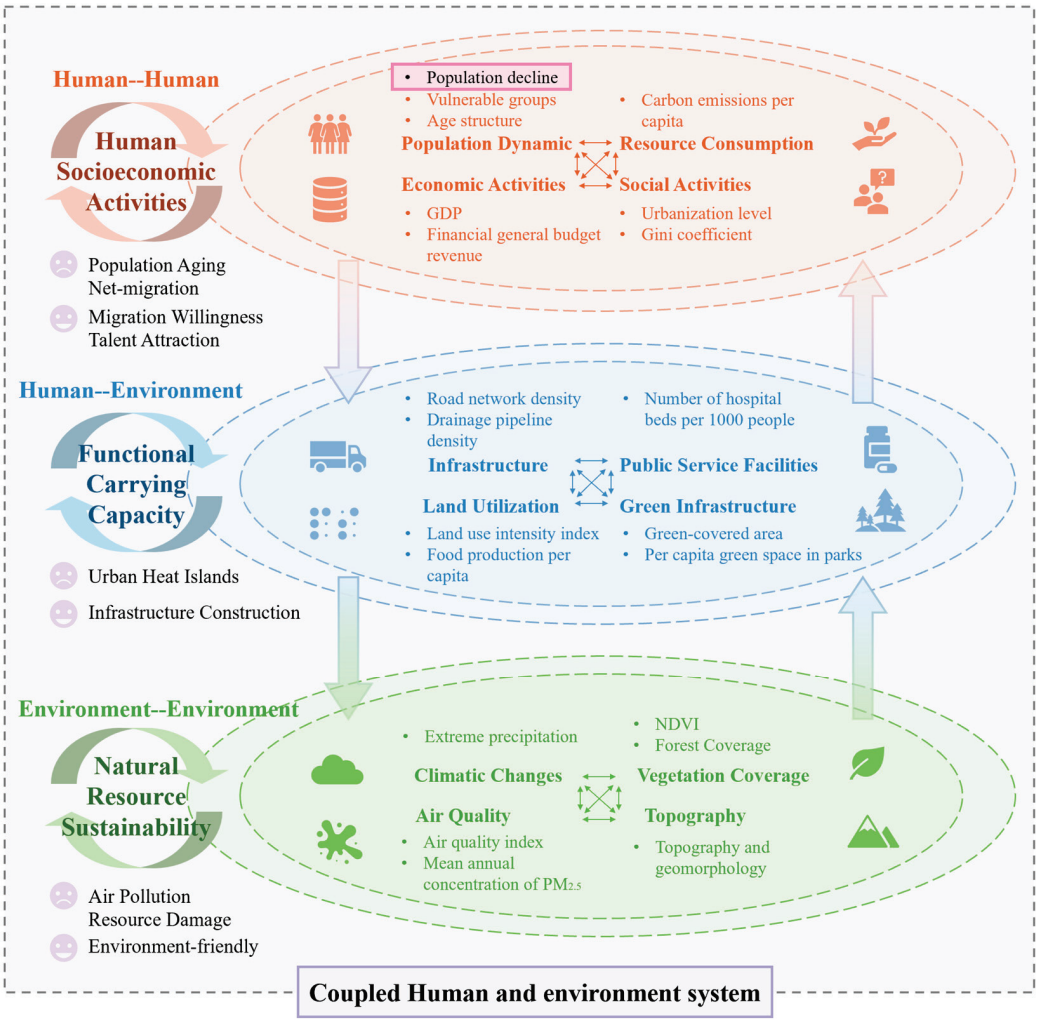

Figure 2. SCTR assessment framework from the perspective of coupled human–environment system.

Resilience theory has become a key analytical lens for unpacking the complex processes, consequences, and adaptive responses within coupled human–environment systems [62–65]. It focuses on a system's ability to maintain core functions, adapt to external changes, and transform when necessary. In resilience theory, interactions between human and environmental systems are regarded as key drivers that maintain systemic balance or induce structural transformation [66]. Human socioeconomic activities continuously influence environmental conditions, which in turn feedback to reshape human behavior and institutional responses [67].

County towns, as prototypical coupled human–environment systems, rely on the coordinated functioning of human–human, human–environment, and environment-environment subsystems for their sustainability and resilience [68,69]. These systems demonstrate dynamic regulatory capacities, such as threshold avoidance and adaptive responses to disturbances [70]. Resilience theory offers a powerful framework to explore these nonlinear dynamics and uncover the feedback mechanisms underlying human–environment interactions.

2.4. Methods

This study aims to evaluate SCTR from a coupled human–environment perspective and to conduct an attribution analysis. The research workflow is illustrated in Figure 3.

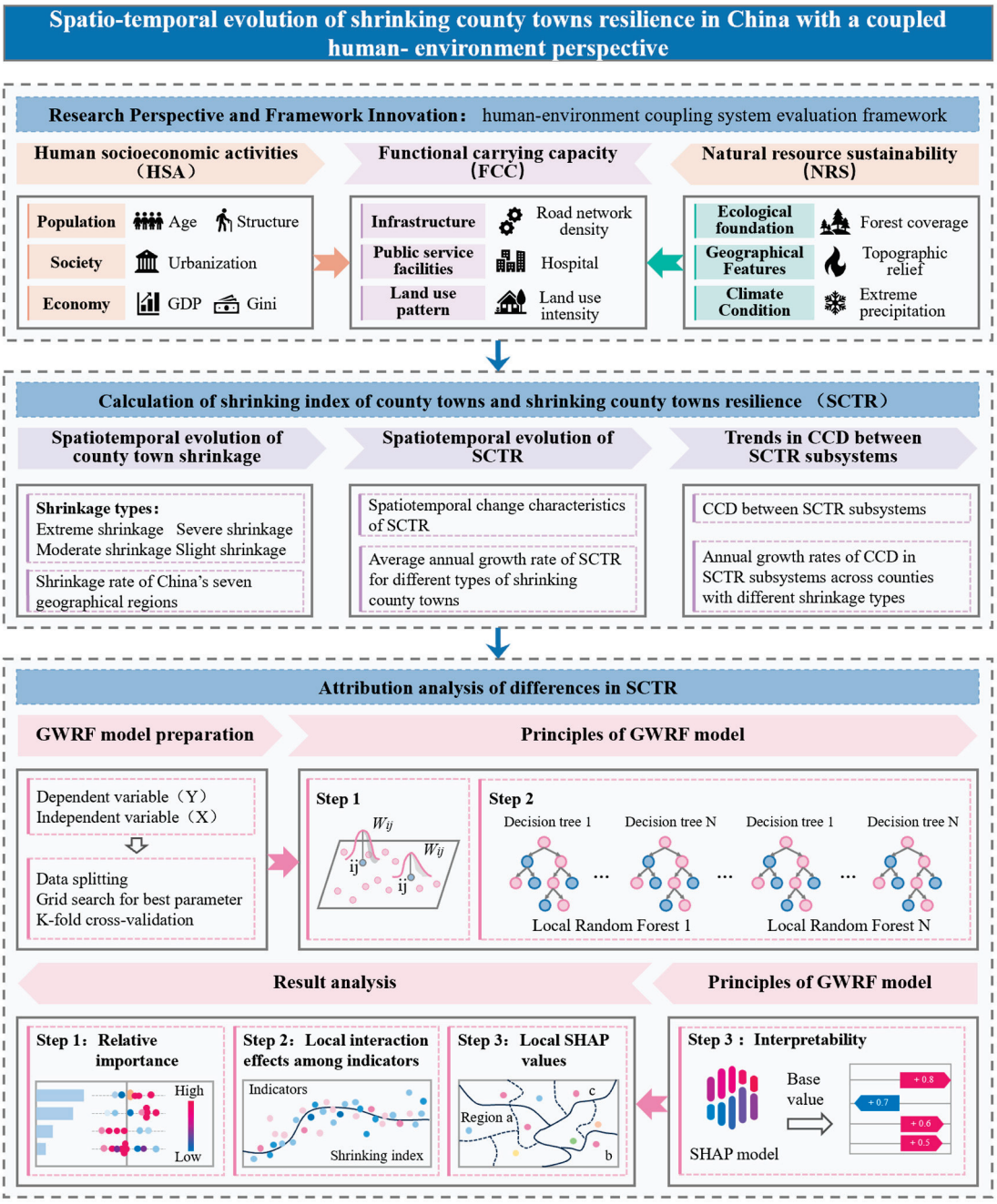

Figure 3. The flowchart of the research process.

2.4.1. Identification and Classification of County Town Shrinkage

Population decline is widely recognized as a primary indicator of urban shrinkage [3,71,72]. In this study, the rate of county towns shrinkage, which is used to determine whether a county town has experienced shrinkage, is calculated as follows:

$$R_i = \frac{pop_{t2} - pop_{t1}}{pop_{t1}} \times 100\% \quad (1)$$

where R_i means the total population change rate for county town between t_1 and t_2 in county town i; pop_{t2} and pop_{t1} denote the total population at the end of the years t_1 and t_2, respectively.

The definition of urban shrinkage adopted in this study is derived from the Shrinking Cities International Research Network (SCIRN). A negative CTSR value signifies that a county town is undergoing shrinkage, with lower CTSR values corresponding to a greater severity of shrinkage.

For a more in-depth analysis of spatiotemporal variations in urban shrinkage across China, the county towns shrinkage rate was categorized into four levels at the spatial dimension [47] (Table 2).

Table 2. Classification of shrinking county towns.

The County Towns Shrinkage Rate	**0~−5%**	**−5~−10%**	**−10~−30%**	**<−30%**
Type	Slight shrinkage	Moderate shrinkage	Severe shrinkage	Extreme shrinkage

2.4.2. Evaluation Model of SCTR

(1) Data standardization and weighting

The index system includes indicators with different measurement units, necessitating the standardization of the indicators prior to the comprehensive evaluation. In this study, the extreme-value method was employed to standardize the data, transforming the values into a range of 0 to 1 to facilitate comparability. The following equations were used:

Positive indicator:

$$Z_{ij} = \frac{X_{ij} - X_{i\ min}}{X_{i\ max} - X_{i\ min}} \tag{2}$$

Negative indicator:

$$Z_{ij} = \frac{X_{i\ max} - X_{ij}}{X_{i\ max} - X_{i\ min}} \tag{3}$$

where Z_{ij} is the standardized value; X_{ij} is the original value of the indicator j; $X_{i\ max}$ and $X_{i\ min}$ are the maximum and minimum values of indicator j, respectively.

The Entropy Weight Method offers an objective approach to weighting, effectively mitigating errors caused by subjective factors [40]. The smaller the entropy value calculated by the entropy weight method, the greater the weight of the index, and vice versa [73]. The Entropy Weight Method is used to calculate the information entropy and weight for each indicator, with the following formula:

The indicator's information entropy is calculated as follows:

$$P_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}} \tag{4}$$

where P_{ij} is the proportion of the *ith* county to the whole under the *jth* indicator (%); n is the total number of counties.

$$e_j = -k\sum_{i=1}^{n} p_{ij} ln(p_{ij}), j = (1, \ldots, m) \tag{5}$$

$$k = \frac{1}{ln(n)} \tag{6}$$

where e_j is the information entropy of the *jth* indicator satisfying $e_j \geq 0$; k is a calculated coefficient; j is the *jth* county resilience indicator; and m is the number of indicators.

Indicator weights are determined as follows:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m} 1 - e_j} \tag{7}$$

where e_j refers to information entropy redundancy; and w_j is the weight of each indicator.

(2) Calculation of SCTR

The SCTR is used to measure shrinking county towns' resilience. The expression is shown in Equation (8):

$$SCTR_i = \sum_{j=1}^{n} Z_{ij} w_j \tag{8}$$

where Z_{ij} is the standardized value of each indicator; n is the number of indicators of the system; w_j is the weight of each indicator; $SCTR_i$ represents the resilience of county town i.

2.4.3. Establishment of an Index System for Evaluating SCTR

Based on the aforementioned theoretical framework, the SCTR evaluation system is structured around three core subsystems: natural resources sustainability (NRS), functional carrying capacity (FCC), and human socioeconomic activities (HAS).

NRS is the most fundamental pillar of resilience in county towns. It encompasses not only basic indicators such as water resource endowment, vegetation coverage, and topographical features, but also places particular emphasis on critical factors like climate adaptability and environmental quality. Through their spatial distribution and interdependent interactions, these natural elements shape the ecological foundation of shrinking counties [74].

FCC refers to the spatial interface between human and environmental systems. It comprises infrastructure, public service facilities, and land use patterns. Collectively, these elements define the capacity of county towns to support population agglomeration and socioeconomic activities. They form a vital foundation for the stable operation of the entire system.

HAS includes population dynamics, economic performance, resource consumption, and social interaction. The system assesses migration trends, population growth rates, and shifts in age structure under conditions of shrinkage. In the economic dimension, it considers both growth potential and the equitable distribution of wealth [75]. Additionally, patterns of resource consumption and social interactions are included to capture the impact of human activities on the human–environment relationship. As shown in Table 1, the SCTR evaluation framework integrates NRS, HAS and FCC. This framework provides theoretical and practical guidance for improving human–environment coordination in shrinking counties, ultimately contributing to the sustainable development of county towns.

Based on collinearity testing conducted using SPSS (version 24) software, indicators with a VIF > 7.5 [76], including the number of permanent residents, proportion of young people, and night-time lighting index, were excluded. The final evaluation system includes 26 robust indicators, forming a scientifically grounded framework for assessing the SCTR (Table 3).

Table 3. Evaluation indicator system for SCTR.

Subsystem Layer	Indicator Layer	Unit	Weight	Attribute	VIF
HSA	(X1) County towns shrinking rate [1]	%	0.05556	+	1.035
	(X2) Proportion of vulnerable groups [2]	%	0.02311	−	2.012
	(X3) Number of students enrolled in ordinary primary school	person	0.05310	+	3.184
	(X4) Population density	person/km^2	0.01472	−	1.014
	(X5) Financial general budget revenue	yuan	0.09710	+	3.168
	(X6) Per capita carbon dioxide emissions	ton/person	0.04040	−	1.150
	(X7) GDP per capita	yuan	0.05263	+	2.596
	(X8) Gini coefficient	-	0.06694	+	2.441
	(X9) Urbanization rate	%	0.07167	+	1.766
	(X10) Annual number of business registrations	-	0.07456	+	1.339
	(X11) GDP	yuan	0.07680	+	5.786
FCC	(X12) Food production per capita	ton/person	0.01770	+	1.506
	(X13) Proportion of urban built-up land	%	0.00855	−	4.067
	(X14) Number of hospital beds per 1000 people	bed	0.01217	−	1.300
	(X15) Green-covered area as percentage of built-up area	%	0.01382	+	1.715
	(X16) Road network density	km/km^2	0.07341	−	2.033
	(X17) Per capita green space in parks	km/km^2	0.02050	+	1.331
	(X18) Drainage pipeline density in built-up areas	km/km^2	0.03302	+	1.148
	(X19) Number of beds in social welfare institutions	bed	0.00849	+	1.846
NRS	(X20) Forest coverage	%	0.04125	+	4.541
	(X21) Water coverage	%	0.03961	+	1.222
	(X22) NDVI	-	0.01501	+	4.127
	(X23) Extreme precipitation [3]	day	0.04542	−	3.005
	(X24) Topographic relief [4]	°	0.02042	−	2.892
	(X25) Air quality index	-	0.01749	+	2.281
	(X26) Mean annual concentration of PM2.5	μg/m^3	0.00654	−	2.176

"+" or "−" indicates whether the indicator has a positive or negative influence on the construction of SCTR. [1] The definition and calculation method of urban shrinkage rate are provided in Section 3.3.1. [2] The proportion of the population in county towns aged under 15 and over 60 in relation to the total population. [3] The number of days in a year when daily precipitation exceeds the 95th percentile of the annual daily precipitation. [4] The elevation difference between the lowest and highest points.

2.4.4. Coupling Coordination Degree Model (CCD)

Subsystems exert mutual influences on one another and collectively determine the overall level of SCTR. A high level of coupling and coordination among these resilience subsystems serves to enhance urban resilience [77,78]. Coupling Coordination Degree (CCD) serves as an established metric used to quantify and evaluate the degree of coordination and coupling among two or more systems [79]. To inform the construction of SCTR, we employ the CDD to evaluate the coordination degree among subsystems. The formula is constructed as follows:

$$C = \left\{ \frac{U(H) \times U(F) \times U(E)}{[U(H) + U(F) + U(E)]^3} \right\}^{\frac{1}{3}} \tag{9}$$

$$T = \alpha U(H) + \beta U(F) + \omega U(E), \alpha + \beta + \omega = 1 \tag{10}$$

$$CCD = \sqrt{C \times T} \tag{11}$$

where C is the coupling degree of the SCTR complex system, with values ranging from 0 to 1; T reflects the degree of complementary relationship among subsystems; α, β, ω represent undetermined coefficients, denoting the contribution of each subsystem.

The overall SCTR level fundamentally relies on the interdependence and coordinated operation of the three subsystems. No subsystem can independently determine the overall resilience; any imbalance in the coordination of one subsystem will limit the effectiveness of the others. Therefore, we assumed that the three subsystems hold equivalent importance, thus setting $\alpha = \beta = \omega$.

To more effectively evaluate the coupling level and coordinated development degree among the three subsystems, this study adopts a classification scheme proposed by previous studies [78]. The evaluation criteria are presented in Table 4.

Table 4. Different types of coupling degree.

Coupling Degree	Type
$C \in [0, 0.2]$	Poor coupling
$C \in (0.2, 0.4]$	Weak coupling
$C \in (0.4, 0.6]$	Basic coupling
$C \in (0.6, 0.8]$	Good coupling
$C \in (0.8, 1.0]$	High coupling

2.4.5. Underlying Mechanisms of Influencing Factors on SCTR

Accurately revealing the impacts of influencing factors on SCTR is critically important to advancing resilience-building efforts in these contexts. We contend that in the analysis of SCTR's driving mechanisms, the consideration of nonlinear characteristics and spatial heterogeneity are critical prerequisites for safeguarding the credibility of attribution findings.

While machine learning models excel at capturing nonlinear correlations between variables [80], they are plagued by two notable limitations. First, they often fail to account for the inherent spatial heterogeneity of geospatial variables [81]. Second, their 'black-box' nature has been widely criticized in the literature [82]. These shortcomings not only constrain their utility in spatial data modeling but also undermine the credibility of attribution outcomes [83]. By comparison, the Geographically Weighted Random Forest (GWRF)—a spatial machine learning (SML) approach—enables robust interpretation of the spatial heterogeneity exhibited by variable importance [84]. Concurrently, the SHapley Additive exPlanations (SHAP) framework facilitates substantial improvements in the interpretability of machine learning models without sacrificing model predictive accuracy [85,86]. Together, these considerations highlight that the combined application of GWRF and SHAP offers significant potential for addressing key challenges in SCTR attribution. These include identifying nonlinear relationships, analyzing spatial heterogeneity, and enhancing model interpretability.

(1) GWRF model

The GWRF model combines the nonlinear feature learning capability of Random Forest (RF) with the spatial weighting mechanism of Geographically Weighted Regression (GWR) [81,87]. This integration allows the GWRF to pinpoint critical environmental predictors and uncover the spatial variability patterns of these predictors across diverse regions [88,89].

Both spatially weighted variables and original characteristic variables were utilized as independent variables [90,91]. We divided the dataset into training (80%) and test sets (20%), ensuring model reliability and generalizability [90,91]. Through repeated experiments, the number of decision trees (ntree) for the GWRF model was set to 500, as this configuration consistently yielded strong predictive performance. For regression

tasks, the number of variables sampled at each split (mtry) was set to one-third of the total number of predictors—given 26 predictors in this study, mtry was determined to be 8. This parameter setting helps reduce prediction errors and enhance model stability [92].

The mathematical formulation of GWRF is as follows:

$$Y_i = a(u_i, v_i) + \varepsilon_i \tag{12}$$

where $a(u_i, v_i)$ represents the prediction of the RF model calibrated at location i, and (u_i, v_i) denotes the coordinates of spatial unit i, and ε_i is the error term.

Additionally, the Grid Search and K-fold cross-validation method was utilized to determine the optimal parameters of the GWRF—a strategy that mitigates the risks of overfitting and data imbalance. The performance indices included the R-squared (R^2), Root Mean Squared Error ($RMSE$) and Mean Absolute Error (MAE). Table 5 indicates the optimized parameters and performance of the GWRF model.

$$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \overline{y}_i)^2} \tag{13}$$

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(y_i - \hat{y}_i)^2}{n}} \tag{14}$$

$$MAE = \frac{\sum_{i=1}^{n} |y_i - \hat{y}_i|}{n} \tag{15}$$

where y_i is the statistical value of SCTR i, $\hat{y}_i$ is the sum of the weight simulation values of each cell of county i, and $\overline{y}_i$ is the average value of SCTR.

Table 5. Optimized parameters and performance of the GWRF model.

Ntree	mtry	RMSE	MAE	R^2
500	8	0.0543	0.0389	0.8122

(2) SHAP value interpretation

SHAP functions as a game theory-derived framework for interpreting machine learning model predictions, achieved by allocating each feature's contribution across the entire set of inputs [85,86] To address the limitations associated with the "black box" characteristic of machine learning models, the SHAP model is integrated with the GWRF model. The calculation formula for the Shapley value of feature i is as follows:

$$\varnothing_i = \sum_{S \subseteq N \setminus \{i\}} \frac{|S|!(|N| - |S| - 1)}{|N|!} [f_x(S \cup \{i\}) - f_x(S)] \tag{16}$$

where $\varnothing_i$ denotes the Shapley value of the i-th feature; S represents a subset of N that excludes the i-th feature; $f_x(S \cup \{i\})$ is the model output when the i-th feature is included; $f_x(S)$ is the model output excluding the i th feature.

The GWRF model and SHAP were redeveloped using Python 3.11 and libraries like scikit-learn and shap.

3. Results

3.1. Spatiotemporal Evolution of County Town Shrinkage

From 2013 to 2022, the number and severity of shrinking towns across China rapidly increased as shown in Figure 4. During the specific time period of 2013–2016, 240 county

towns experienced population shrinkage. Among them, slight shrinkage was the predominant type, accounting for 54.16% of all shrinking county towns. Between 2016 and 2019, the number of shrinking county towns rose to 418, constituting 28.4% of the total. However, from 2019 to 2022, 694 county towns experienced shrinkage, with the proportion rising sharply to 47.15%. The number of moderate and extreme shrinkages has increased significantly, accounting for 17.87% and 23.06% of all shrinking county towns, respectively. From 2013 to 2022, a total of 604 county towns in China experienced shrinkage, accounting for 41.04% of the national total. Overall, county town shrinkage in China is significant, indicating a serious and accelerating trend, with slight and moderate shrinkage being the most predominant types.

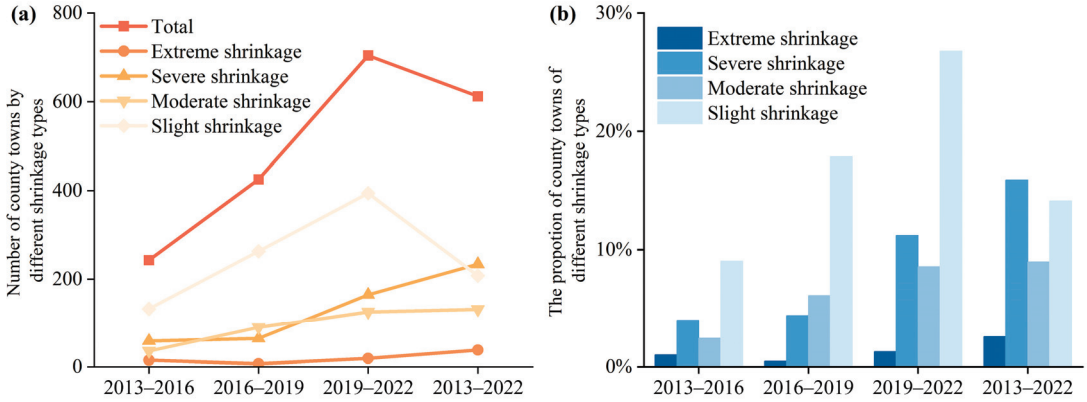

Figure 4. The number and severity of shrinking towns in China. (**a**) The number of county towns by different shrinkage types; (**b**) The proportion of county towns of different shrinkage types.

The spatiotemporal distribution of shrinking county towns in China exhibited significant regional disparities from 2013 to 2022, as illustrated in Figures 5 and 6 Since 2013, shrinking county towns are primarily distributed across four regions: China's Northeast, Northwest, Southwest, and North. Over time, both the number and severity of shrinking counties in these four regions have increased significantly. This has resulted in clearly identifiable and contiguous contraction zones. Among them, Northeast China experienced the most severe shrinkage, with approximately 89% of its county towns undergoing population shrinkage over the decade. This is largely attributed to the high concentration of resource-dependent towns, where the dual challenges of resource depletion and lagging industrial restructuring have led to substantial population shrinkage. County towns in the Southwest and in the Shaanxi–Gansu–Ningxia region of the Northwest have shown a clear trend of worsening shrinkage, evolving from slight to moderate, and in some cases, severe levels. Central and Eastern China exhibited widespread localized shrinkage, particularly in the provinces of Hubei, Hunan, and Jiangxi. Additionally, a small number of county towns in Guangdong and Guangxi also experienced severe shrinkage. Driven by population siphoning effects, county towns in Central, Eastern, and Southern China are experiencing sustained population outflows toward adjacent metropolitan areas. This contributes to emerging patterns of shrinkage across these regions.

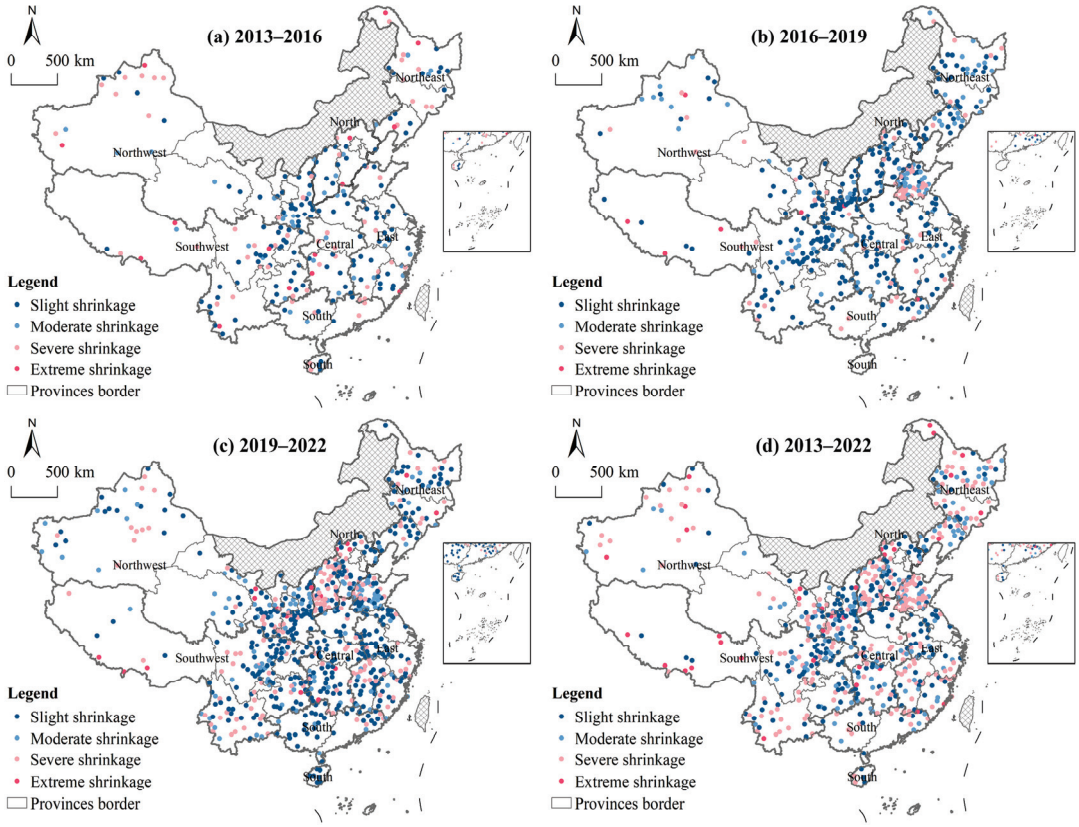

Figure 5. Spatial distribution of shrinking towns in China, from 2013 to 2022.

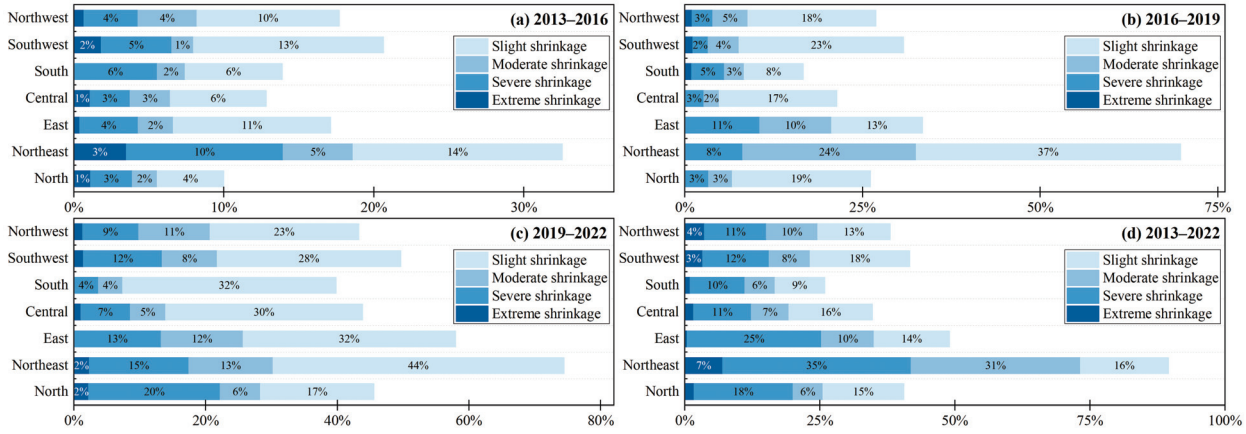

Figure 6. Number and degree of shrinking towns in different regions, from 2013 to 2022.

3.2. Spatiotemporal Evolution of SCTR

3.2.1. Temporal Dynamics Characteristics of SCTR

Figure 7a shows the temporal trend of SCTR from 2013 to 2022. Overall, the SCTR value showed a modest but steady upward trend, rising from 0.219 in 2013 to 0.268 in 2022. However, the overall SCTR value remained low. This indicates that, while resilience-oriented urban development policies have been implemented, significant gaps remain in building resilience for shrinking county towns. Over time, the disparity in SCTR levels has grown more pronounced. To analyze temporal variations in resilience subsystem scores for SCTR, we visualized their trends separately (Figure 7b–d). First, the HSA subsystem displayed a fluctuation pattern similar to that of overall SCTR. This suggests that HSA plays a critical role in SCTR development. Additionally, the average value of NRS showed a slight downward trend, staying around 0.05. This reveals a growing imbalance between

socioeconomic development and environmental sustainability. Finally, the FCC showed an annual increase, with the average value rising from 0.015 in 2013 to 0.026 in 2022. This illustrates that the continuous strengthening of state support has positively impacted socioeconomic development.

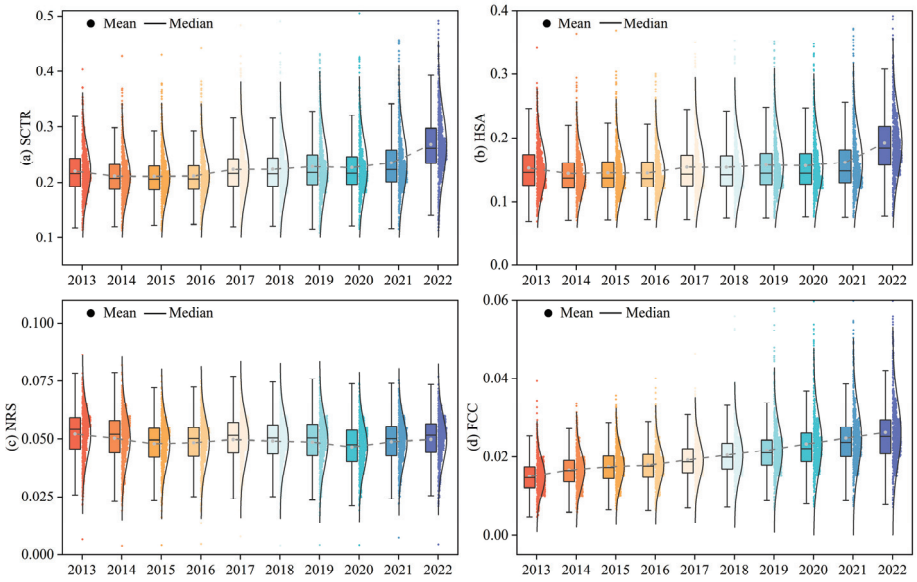

Figure 7. The temporal evolution trend of SCTR from 2013 to 2022.

3.2.2. Spatial Distribution Characteristics of SCTR

To characterize the spatial distribution of SCTR, we visualized the data for 2013, 2016, 2019, and 2022, as shown in Figure 8a–d. We used the average natural breakpoints of the SCTR composite index over four years as the classification standard for our spatial mapping [25]. From 2013 to 2022, SCTR exhibited significant spatial disparities in China. In 2013, only 17.35% of shrinking counties exhibited medium-high or high resilience, concentrated mainly in the northeastern and southeastern coastal regions. Notably, by 2016, SCTR showed a slight decline, with only 9.98% of county towns exhibiting high or moderate SCTR levels. This indicates that county towns shrinkage has exerted adverse effects on SCTR. Based on the observed changes in SCTR subsystems, it is evident that the challenges in building SCTR go beyond population shrinkage and economic decline. They may also exacerbate social issues, intensify resource scarcity, and reflect inadequate policy support, undermining county governments' capacity to manage future risks. In 2022, the second year following the conclusion of China's 13th Five-Year Plan, SCTR levels rose significantly. The proportion of shrinking counties with medium-high or high resilience increased to 53.03%. Using the Hu Line (the Heihe-Tengchong Line) as a geographic reference, counties with higher resilience levels were predominantly located east of the line. In contrast, counties with lower resilience were concentrated in economically underdeveloped regions, including western Sichuan, Gansu, Qinghai, Tibet, and Xinjiang.

This study compares the SCTR and subsystem resilience across different regions during the study period (Figure 9). In general, both the SCTR and FCC resilience across all regions of China have exhibited a marked improvement, indicating that China's urban resilience efforts have achieved phased outcomes. Notably, between 2017 and 2020, NRS resilience across all seven regions experienced a significant decline. To pinpoint the key factors driving this decline in NRS resilience, this study calculated the average rate of change for each indicator within the NRS subsystem over this period. The results show that the two indicators with the highest average change rates are air quality (32.66%) and extreme precipitation (20.84%). The findings suggest that air pollution and extreme climate

conditions are the primary factors limiting NRS resilience improvement in shrinking county towns in China. From 2017 to 2020, some shrinking counties in China were still undergoing industrial transformation [93]. Emissions from traditional energy-intensive industries, such as regional chemical production and building materials processing, had not been fully controlled, making them major contributors to fixed pollution sources. Between 2018 and 2019, Typhoons Lekima and Mangkhut struck the southeastern coastal regions of China sequentially [94]. In 2020, the southwestern, northwestern, and northern regions experienced rare heavy rainfall, which triggered mountain floods and geological disasters in some areas [95–97].

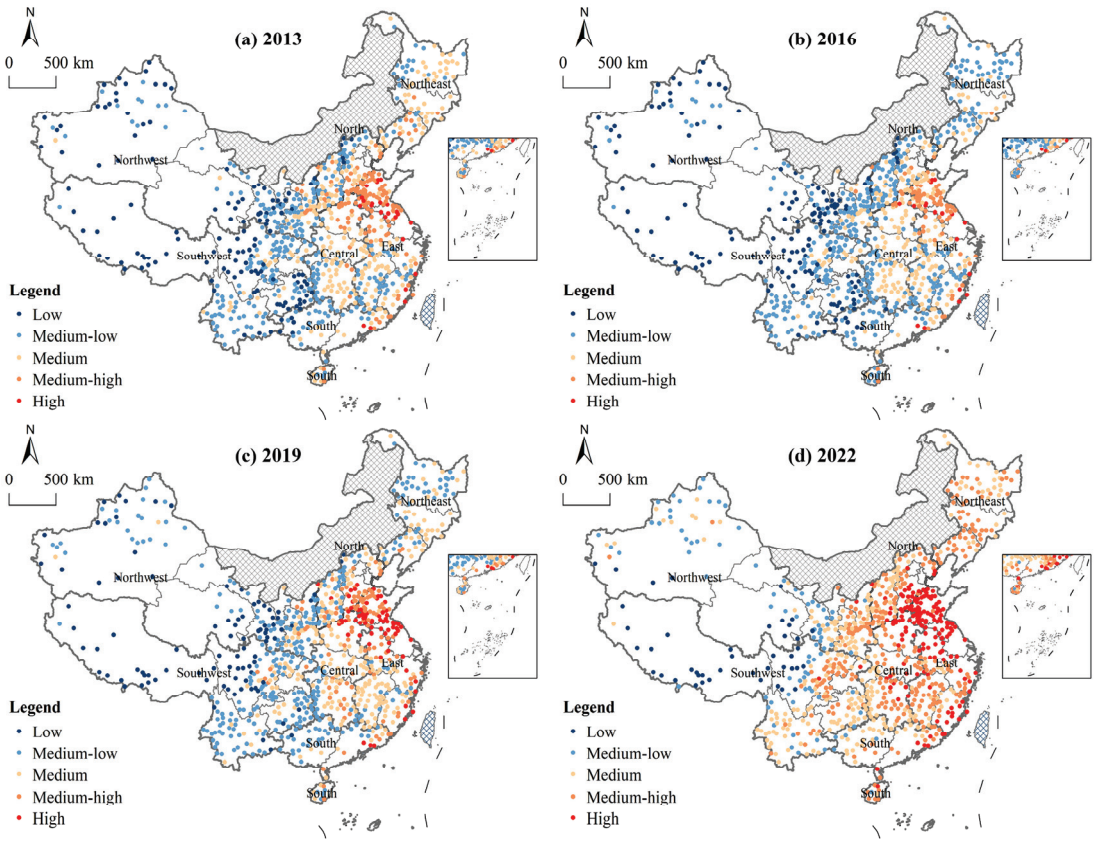

Figure 8. Spatial distribution of SCTR values in China.

3.2.3. Changes in the Growth Rate of SCTR

The average annual growth rate of SCTR from 2013 to 2022 was analyzed, with the results categorized using the natural breakpoint method (Figure 10a). Over the past decade, the average SCTR level in China showed modest fluctuations but maintained an upward trajectory. Shrinking county towns with higher annual resilience growth rates were mostly concentrated in the Sichuan–Chongqing–Guizhou region. Notably, while the average SCTR level in central and western China remains relatively low, their annual growth rates are high, particularly in provinces such as Hubei, Hunan, Sichuan, and Gansu. This indicates that while regional disparities in SCTR persist, the gaps are gradually narrowing. The Chinese government has consistently implemented policies to promote coordinated regional development, supporting economic growth in underdeveloped areas and reducing disparities in basic public services. These initiatives have reduced low resilience in central and western regions, contributing to more balanced development across the country.

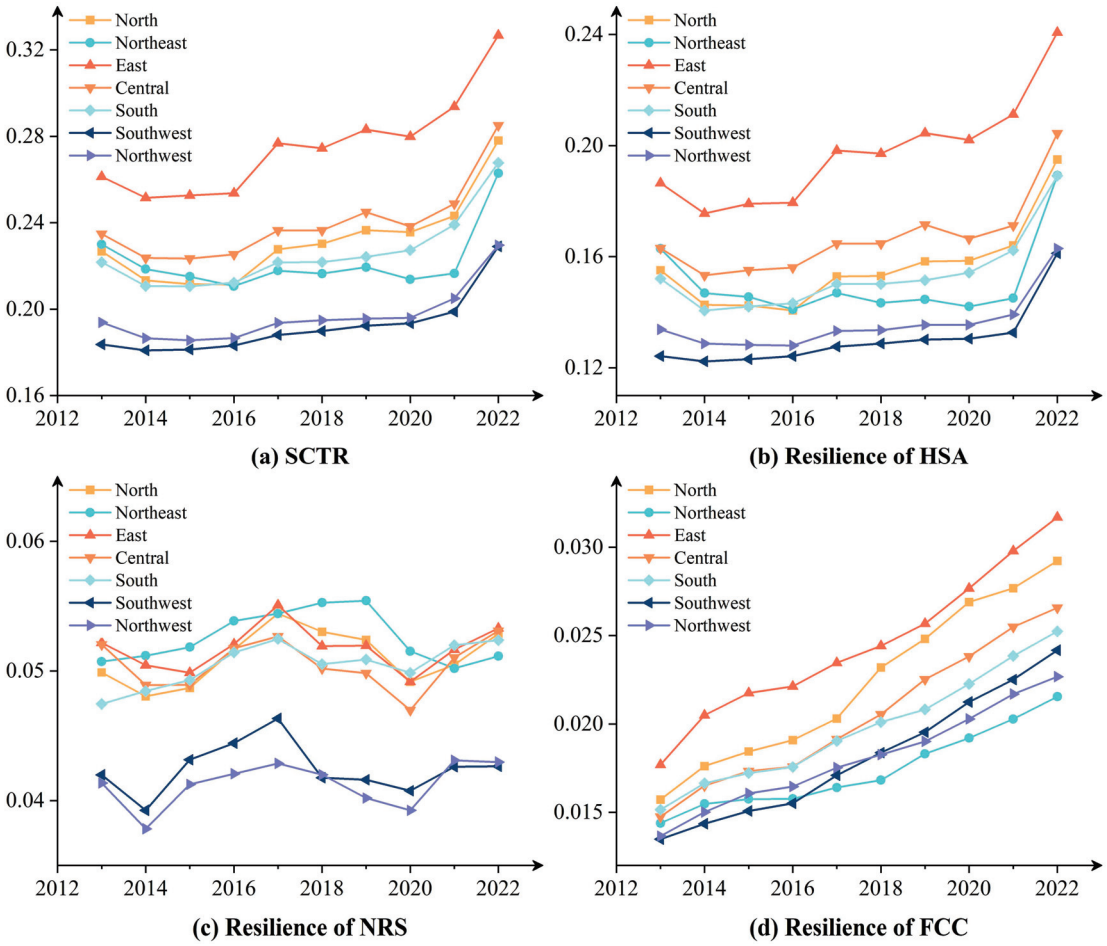

Figure 9. SCTR and resilience of each subsystem in seven regions.

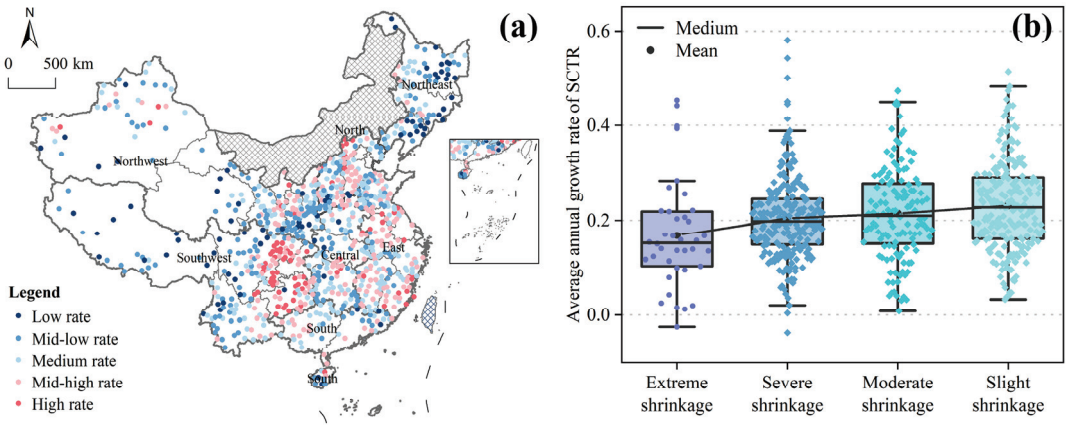

Figure 10. Average annual growth rate of SCTR. (**a**) Spatial distribution of the average annual growth rate of SCTR. (**b**) Average annual growth rate of SCTR by shrinkage type.

We also calculated the average annual growth rate of SCTR by type from 2013 to 2022 (Figure 10b). The resilience growth patterns of shrinking counties show significant spatial heterogeneity. As shrinkage severity increases, the SCTR growth rate tends to decrease, with extreme shrinkage counties showing negative growth. This suggests that more pronounced shrinkage in county towns is strongly linked to a greater negative impact on SCTR. This highlights the need to strengthen external support and implement more comprehensive reform measures to improve SCTR. Additionally, the spatial analysis

in Figure 8 reinforces the significant moderating role of spatial location factors in the relationship between shrinkage and resilience.

3.2.4. Trends in CCD Between SCTR Subsystems

To guide the coupling coordination of human–environment systems in shrinking county towns, we employed the CCD model to calculate the CCD values for SCTR subsystems from 2013 to 2022 [76] (Figure 11a). In general, the CCD of SCTR subsystems shows a consistent upward trend, indicating significant improvements and increasing coordination among the resilience subsystems. However, in 2022, 67.5% of shrinking county towns remained at the basic coupling coordination level, suggesting that coordination between subsystems still requires considerable improvement.

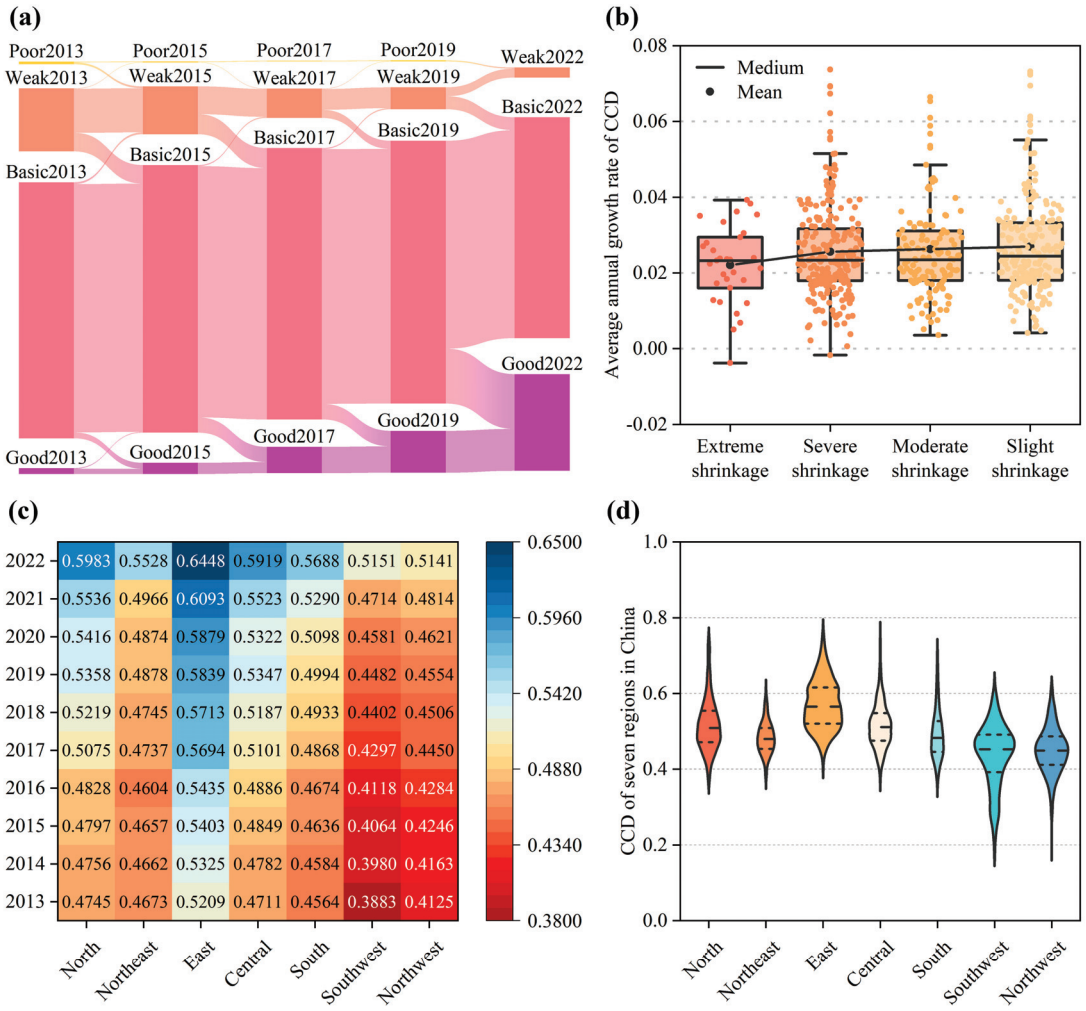

Figure 11. The CCD of SCTR subsystems. (**a**) Temporal changes in the CCD of SCTR subsystems in China. (**b**) Average annual growth rate of CCD in SCTR Subsystems by shrinkage type. (**c**) The CCD of SCTR subsystems across different regions (2013–2022). (**d**) Regional comparison of CCD in SCTR subsystems.

We further analyzed the annual growth rates of CCD in SCTR subsystems across counties with different types of shrinkage (Figure 11b). The results indicate that the severity of shrinkage negatively impacts the annual growth rate of CCD. This finding underscores that population loss disrupts the coupling and coordination mechanisms between human–environment subsystems, constraining the enhancement of county towns' resilience. Comparative analysis of China's seven major regions reveals significant spatial

heterogeneity in CCD levels (Figure 11c,d). From 2013 to 2022, South China consistently had the highest average CCD value (0.570), demonstrating good coordination between human and environmental systems.

In contrast, Southwest and Northwest China had notably lower CCD values of 0.437 and 0.449, respectively, indicating these regions face greater challenges in maintaining coordination under shrinkage pressures. These regional disparities may result from variations in economic development, industrial structures, and policy support across regions.

In general, we argue that county towns demonstrating resilience in HSA, FCC, and NRS are in a phase of synergistic coupling characterized by mutual reinforcement and coevolution. These counties, such as those in East China, typically have relatively prosperous economies and stable societies, which promote population growth. In contrast, a decline in subsystem coupling often signals underdeveloped economic and social conditions, further exacerbating population outmigration. This trend is particularly evident in the Northeast, Northwest, and Southwest regions. This highlights that SCTR results from complex interactions and mutual influences within the human–environment system.

3.3. Mechanisms of Influencing Factors on SCTR

3.3.1. Identification of Key Influencing Factors

This study reveals the nonlinear effects of factors on SCTR. We used the mean absolute SHAP values to quantify each factor's global importance [84,98], and visualized the results using a bar chart (Figure 12). Among all factors, the Gini coefficient (X8) plays a critical role in enhancing SCTR. This may be due to the fact that rising income inequality erodes social capital, intensifies group conflicts, and reduces the efficiency of resource allocation. All of these undermine the capacity of county towns to cope with shocks. In addition to the Gini coefficient, urbanization rate (X9), GDP (X11), forest coverage rate (X20), local general fiscal budget revenue (X5), and extreme precipitation (X23) emerge as primary factors influencing SCTR levels from 2013 to 2022.

We further visualized the SHAP values using a bee swarm plot to illustrate the positive and negative effects of different factors on SCTR (Figure 12). In this plot, each point represents a sample, with the color gradient reflecting the actual value of the corresponding feature (red for high values and blue for low values).

Among the various influencing factors, the Gini coefficient, extreme precipitation, proportion of vulnerable groups, and topographic relief exert significant negative impacts on SCTR. Conversely, urbanization level (X9), GDP (X11), local general fiscal budget revenue (X5), and forest coverage (X20) demonstrate positive impacts on SCTR. These findings suggest that more developed economic structures and higher ecological environment quality play crucial roles in enhancing SCTR. Notably, population growth rate shows a positive correlation with SCTR, indicating that shrinkage undermines SCTR.

We plotted Partial Dependence Plots (PDP) of SCTR influencing factors based on the SHAP model (Figure 13). The PDP diagrams reveal several critical insights: (1) The effect of the population shrinkage rate (X1) on SCTR displays a nonlinear trend, shifting from a positive to a negative correlation. While moderate population growth initially benefits SCTR, once the growth rate exceeds 39%, it begins to have a detrimental effect on SCTR. (2) The effect of urbanization level (X9) on SCTR follows an S-shaped curve, consistent with the classical Northam urbanization curve. Beyond an urbanization level of 41%, its marginal contribution to SCTR gradually diminishes. (3) When NDVI (X20) exceeds 0.49, its positive impact on SCTR becomes significantly more pronounced. (4) The Gini coefficient (X8), a key indicator of income inequality, reflects increasingly unequal wealth distribution as its value rises. When it exceeds 0.8, indicating extreme inequality, its negative marginal effect on SCTR intensifies significantly. In conclusion, these findings highlight the locally

unstable and nonlinear nature of the relationships between key determinants and SCTR, underscoring the need for context-specific resilience strategies.

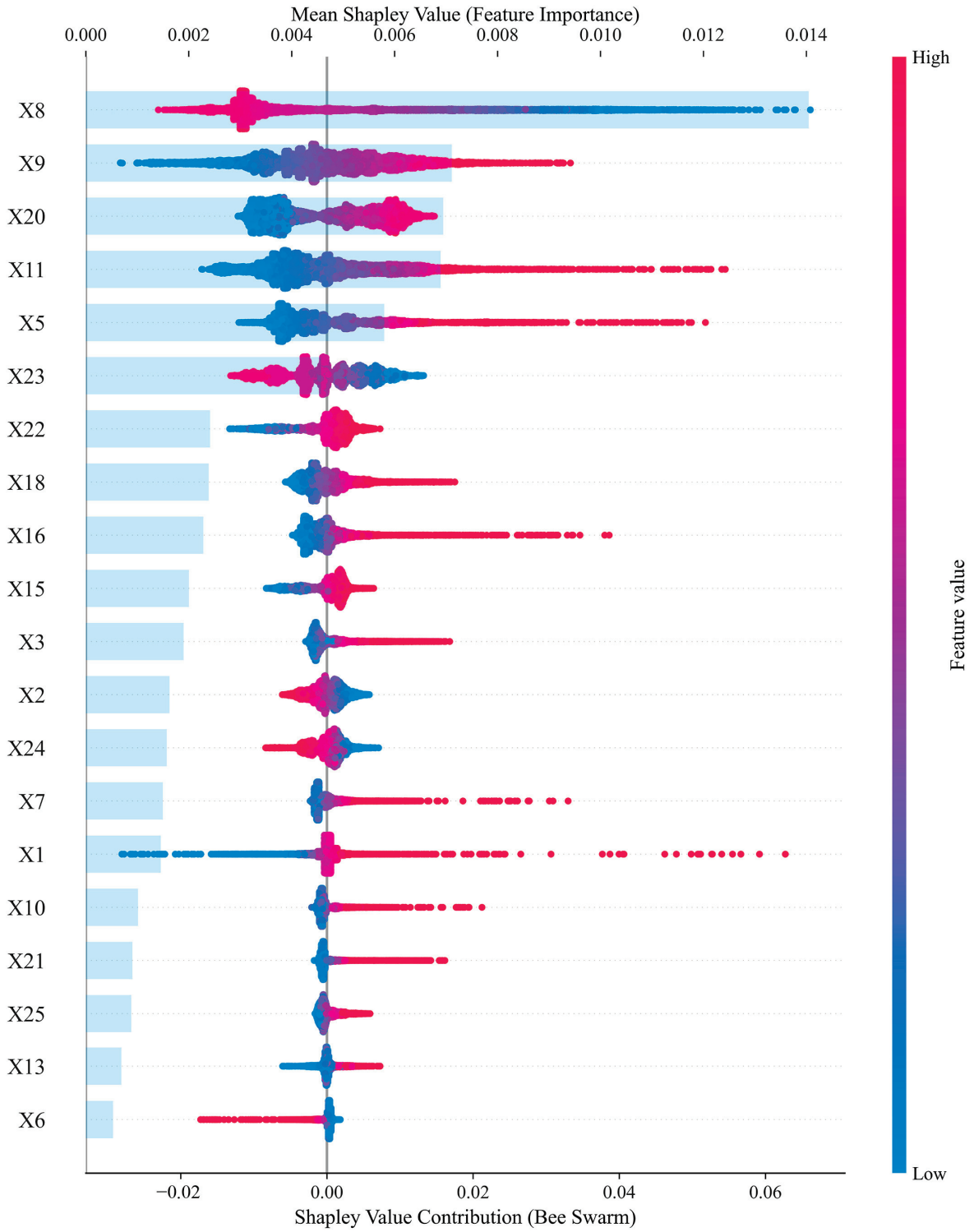

Figure 12. Importance of influencing factors on SCTR from 2013 to 2022.

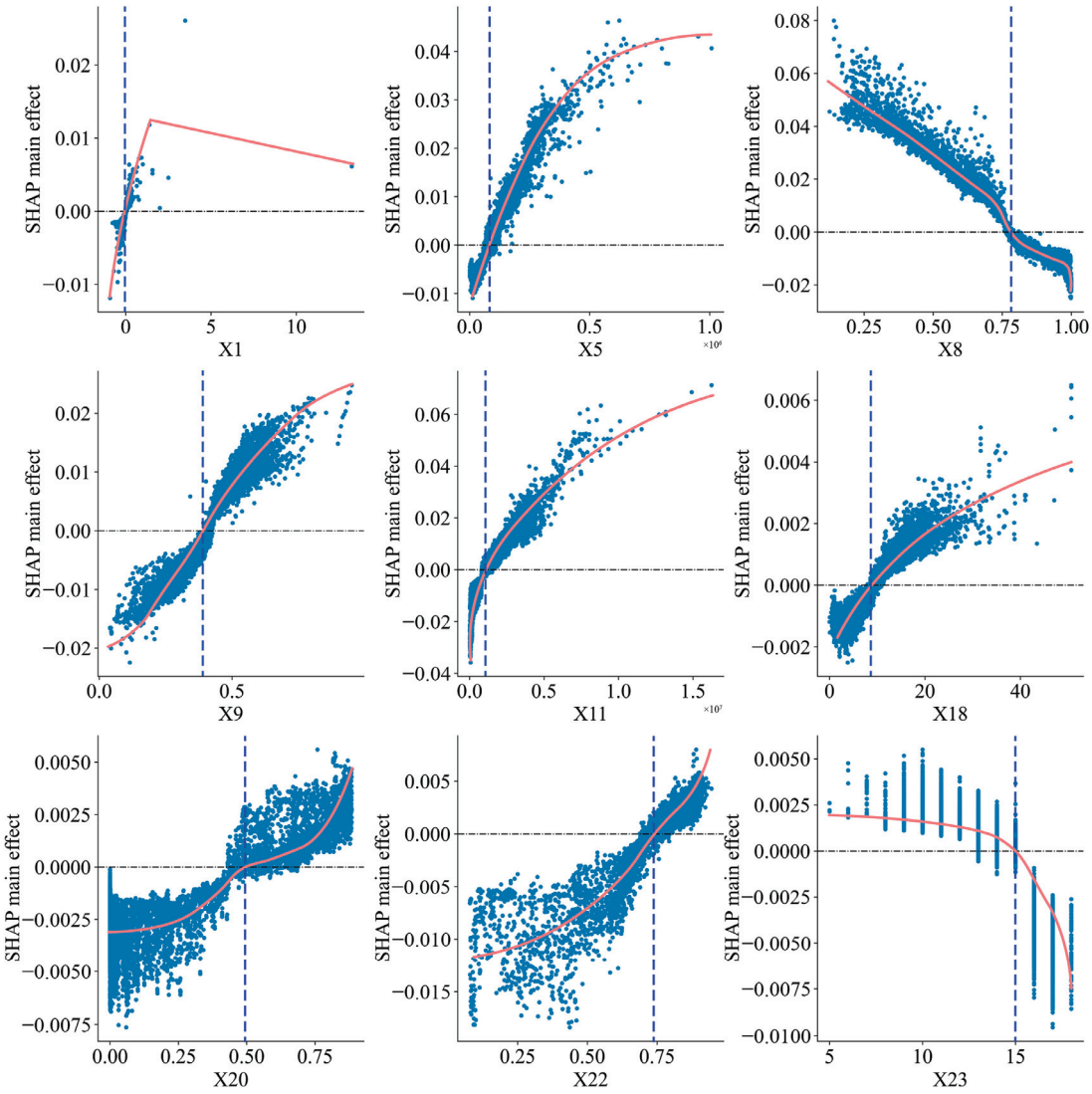

Figure 13. PDPs of SCTR influencing factors.

3.3.2. Attribution Analysis of SCTR Across Different Shrinkage Types

This study further elucidates the differential mechanisms influencing SCTR across various types of shrinking county towns. In general, the factors affecting resilience show slight variations among the four shrinkage types (Figure 14). The Gini coefficient (X8), urbanization rate (X9), GDP (X11), forest coverage (X20), and local government budgetary revenue (X5) have significant effects on the SCTR across all shrinkage types. For slight, moderate, and severe shrinkage, frequent extreme precipitation events exert a notable negative impact on resilience. In contrast, well-developed infrastructure networks can enhance SCTR in these regions, particularly road network density (X16) and urban drainage system coverage (X18). Notably, demographic and socioeconomic factors, such as population decline and age structure, have a more pronounced impact on the resilience of extremely shrinking counties compared to other types. This indicates that in counties experiencing severe population loss, demographic factors have become critical constraints on resilience. Accordingly, mitigating population outflow and maintaining a stable local population have become critical priorities for strengthening resilience in counties experiencing extreme shrinkage.

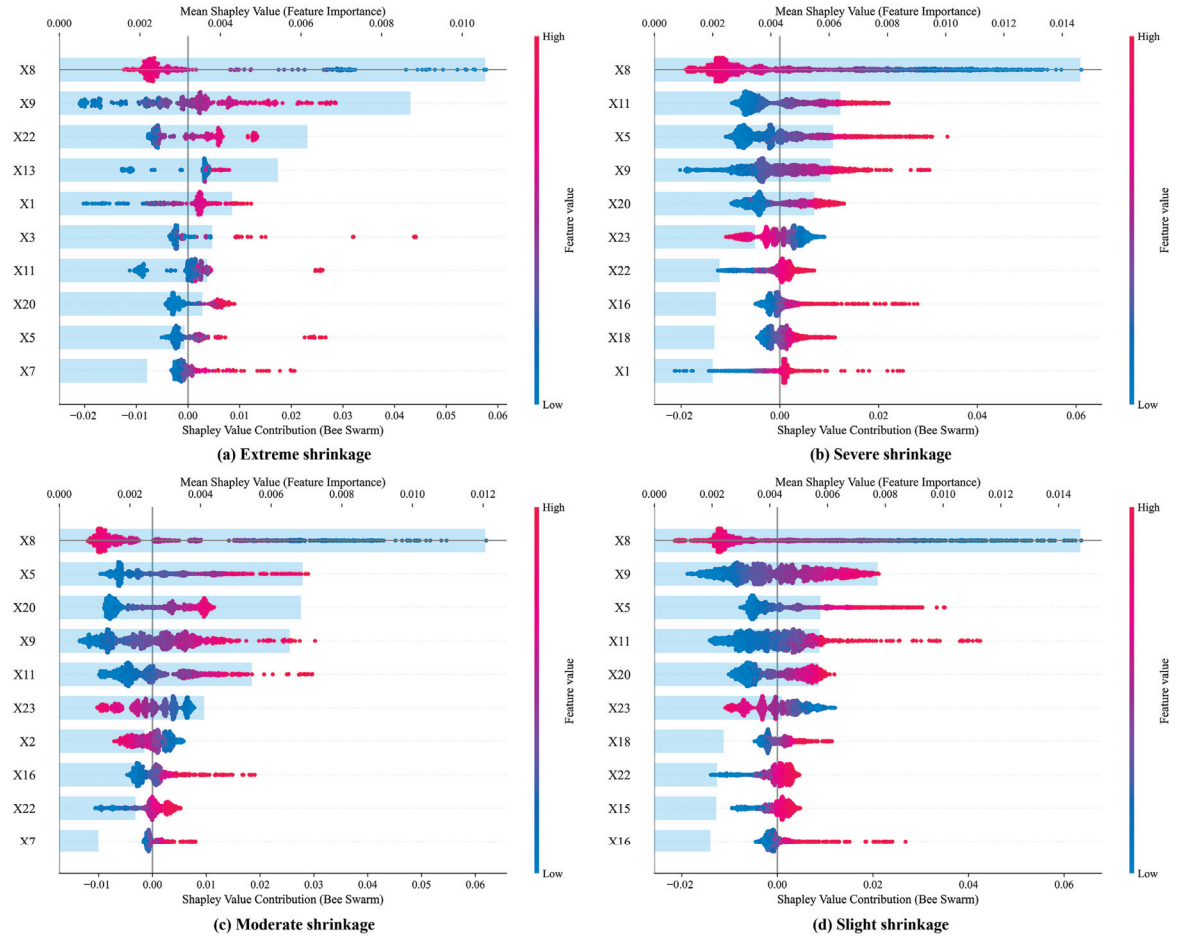

Figure 14. Importance of influencing factors on SCTR across different shrinkage types from 2013 to 2022.

3.3.3. Spatial Heterogeneity Analysis of Key Influencing Factors

This study explores the spatial heterogeneity of the effects of population growth rate (X1), Gini coefficient (X8), urbanization level (X9), GDP (X11), and NDVI (X22) on SCTR.

From a demographic perspective, the impact of the population growth rate on SCTR shows a spatially scattered pattern, without forming significant clusters. This suggests that population shrinkage exerts a broad and generalized effect on SCTR (Figure 15a). High values of the Gini coefficient, which significantly influence SCTR, are clustered in Shandong, Hebei, and parts of the southeastern coastal regions. Notably, its impact on Northeast China has intensified over the study period (Figure 15b). The urbanization level has a more pronounced effect on SCTR in Heilongjiang Province, as well as in North and East China, while its influence in the Shaanxi-Gansu-Ningxia region and the southwestern provinces is weaker (Figure 15c). The spatial distribution of GDP's impact on SCTR reveals a "strong east, weak west" distribution, with East and Central China emerging as key high-value areas. In contrast, its influence in Northeast China has shown a declining trend (Figure 15d). NDVI exerts a stronger influence on SCTR in Northeast China, Yunnan, Sichuan, Chongqing, and the southeastern coastal regions, while its impact in the northwest remains relatively limited (Figure 15e).

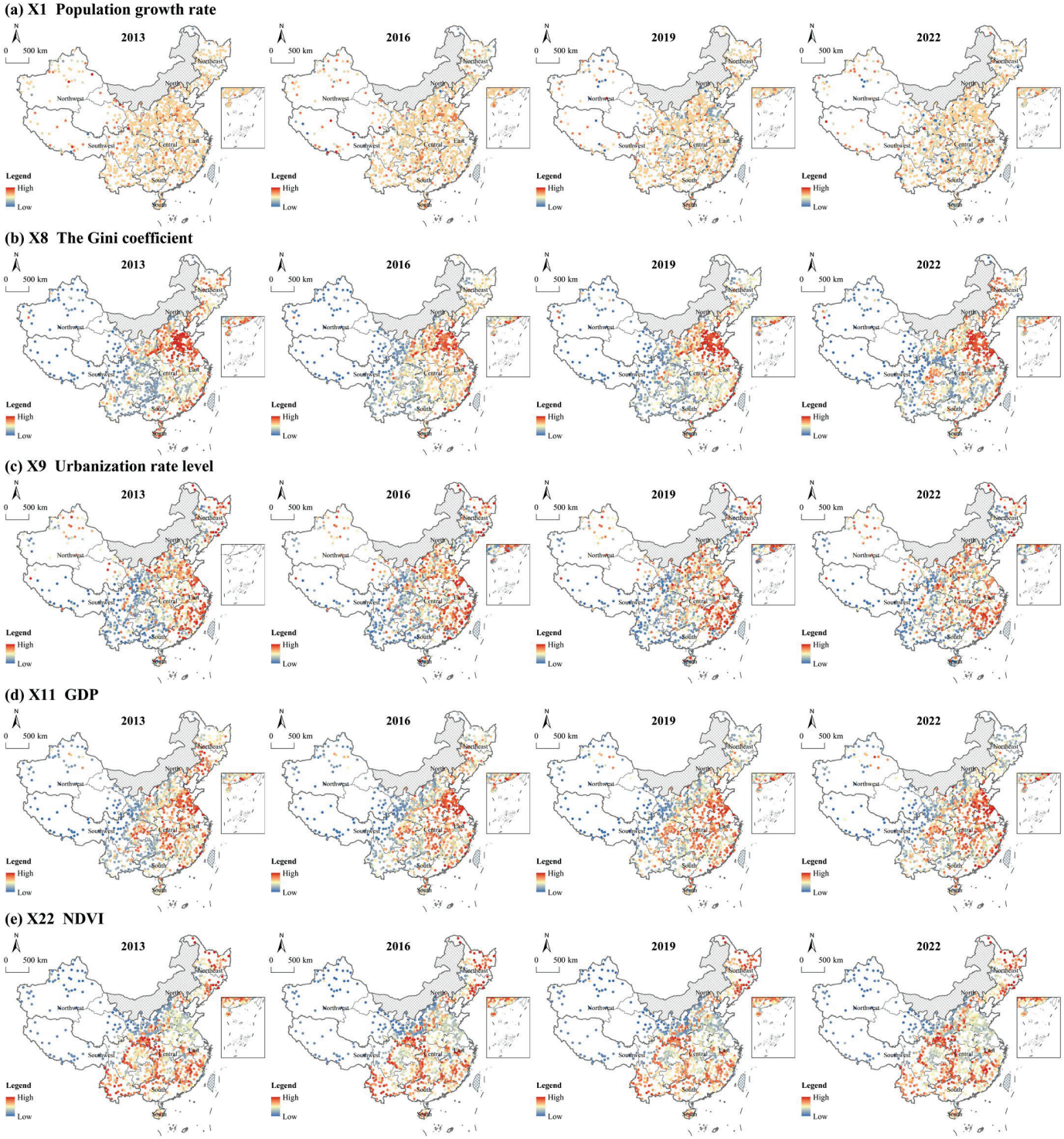

Figure 15. The spatial heterogeneity of key influencing factors on SCTR.

4. Discussion

4.1. The Shrinkage of Counties in China Is Increasingly Intensifying

Amid rapid urbanization, the population decline in China's county towns has become an increasingly pressing issue. Over time, population shrinkage in China has been marked by three key trends: an increasing number of affected towns, deepening declines, and a broader geographic scope. These trends align with the findings of Zhang and Yao [99,100]. It is important to highlight that county town shrinkage is not unique to China; it is, in fact, a common challenge faced by small towns globally during periods of transformation [101].

Between 2013 and 2022, two primary patterns of shrinkage emerged in China's county towns: contiguous decline in the northeastern, northwestern, southwestern, and northern regions, and more localized shrinkage in the central, eastern, and southern regions. This pattern mirrors the trajectory of resource- dependent towns globally, such as Pittsburgh and Detroit in the United States, Manchester and Liverpool in the United Kingdom, and Düsseldorf in Germany's Ruhr area, all of which faced a cycle of "resource depletion—economic decline—population outflow" due to reliance on single industries and delayed transformation [102–104]. Conversely, localized shrinkage largely results from the reallocation of resources driven by the siphoning effect of urban agglomerations. This phenomenon is similar to the population pull exerted by Tokyo on surrounding towns in Japan, or the shrinkage of towns within London's commuter belt in the United Kingdom. The concentration of capital and labor in core cities often leads to the outflow of population from neighboring small towns [46,105,106].

This study reveals that 47.15% of county towns experienced shrinkage, while Li et al. found that the proportion of shrinking cities in China was 30.4% [107]. This indicates that county towns are facing a more severe crisis of shrinkage compared to cities, a conclusion that aligns with the views expressed by Tong et al. [99]. Moreover, the proportion of shrinking county towns increased sharply between 2019 and 2022, likely due to the adverse economic and social effects of the COVID-19 pandemic. The pandemic intensified the closure of small enterprises in county towns, reducing employment opportunities and accelerating population migration to cities. This impact, not unique to China, has been observed globally, with similar patterns emerging in small towns in southern Italy and non-metropolitan counties in South Korea [108]. These findings highlight the increased vulnerability of county towns to external risks, as well as their heightened sensitivity to macroeconomic fluctuations and policy shifts. This conclusion applies to most small towns worldwide. Consequently, strengthening the SCTR has become a critical issue that must be addressed.

4.2. Differentiated Characteristics and Key Influencing Mechanisms of SCTR

Enhancing the SCTR is a crucial strategy for these towns to withstand external disturbances and mitigate risks, making it an essential component of sustainable development [109]. This study examines the spatial–temporal characteristics of SCTR and the interactions among resilience subsystems. It also explores the mechanisms through which various factors influence resilience from a human–environment coupling perspective. These issues represent the core scientific questions in advancing resilience-building efforts in shrinking county towns.

From a temporal perspective, the SCTR in China has shown a slight upward trend, though it remains at a relatively low level. Notably, resilience subsystems display a differentiated pattern: "increased FCC, HSA volatility, and declining NRS." Zheng and Chen found that economic and social resilience in most Chinese cities lags behind ecological resilience, which contrasts with the findings of this study [110,111]. This discrepancy is attributed to path dependence driven by policies and development models. Economic development in shrinking county towns has largely been characterized by extensive growth, with a focus on economic benefits at the expense of ecological protection, leading to a decline in NRS. Furthermore, research indicates that air pollution and extreme precipitation between 2017 and 2020 were major contributors to the decline in NRS. This supports Rao et al.'s view that shrinking cities face compounded challenges from both climate change and human activities [72].

It is worth noting that major strategies, such as new-type urbanization, poverty alleviation, and rural revitalization, have accelerated infrastructure development and

economic growth in county towns. The governance capacity of local governments and related policies directly influence the degree of shrinkage and resilience-building efforts in these towns [72,112]. In terms of economic resilience, China's shrinking county towns have received substantial policy support, particularly in FCC, thus maintaining overall stability during transformative periods [101,112]. This contrasts with the market-driven resilience enhancement pathways typically seen in Europe and North America [113–115].

Spatially, the SCTR exhibits a clear division along the Hu Line: with higher resilience in the east and lower resilience in the west. This pattern is closely linked to China's regional development imbalance. Moreover, we observe that the annual growth rate of resilience is higher in central and western regions, which indicates the positive outcomes of China's regional coordination policies. Policies such as the Western Development Strategy have played a key role in promoting the development of county towns in these areas through strategies such as transfer payments, industrial support, and infrastructure investment.

The greater the population shrinkage in a county town, the slower its resilience growth rate. In cases of extreme shrinkage, resilience can even experience negative growth. For example, extreme shrinking towns in Hokkaido, Japan, have faced a decline in public services and reduced industrial vitality due to continuous population outflow, ultimately entering a vicious cycle of diminishing resilience [116]. Similarly, small towns in eastern Germany, located along the border, have experienced infrastructure idling and economic stagnation due to population loss, resulting in persistently low resilience levels [117–119].

Research on the coupling and coordination of SCTR subsystems reveals that the subsystems in China's shrinking county towns are still in an adjustment phase. Conflicts between economic development, spatial construction, and ecological protection continue to hinder the coordinated development of resilience systems, ultimately affecting the overall SCTR. This finding aligns with the work of Shi and Liu [118,119]. As population shrinkage increases, the coordination between resilience subsystems decreases. Population loss disrupts the relationship between labor, industry, and resources, leading to a failure in synergy among the three subsystems. This highlights that population decline is a key trigger for human–environment decoupling, underscoring the importance of using a human–environment coupling perspective to analyze the SCTR.

Understanding the mechanisms and spatial heterogeneity of the key factors influencing the SCTR is essential to enhancing overall resilience. The impact of population decline is spatially dispersed, highlighting the widespread effects of population shrinkage on the SCTR. However, population loss has emerged as a critical factor driving extreme and severe shrinkage. The Gini coefficient shows high values concentrated in regions such as Shandong, Hebei, and the southeastern coastal areas. This is primarily due to the coexistence of advanced manufacturing and traditional agriculture in these regions, which exacerbates income inequality and weakens the resilience of county towns. Additionally, the northeastern region, reliant on resource-based industries that have declined, exhibits lower economic development quality, resulting in a weakened driving force of GDP in resilience-building efforts.

4.3. Recommendations for Enhancing the SCTR in Different Regions

Policymakers should avoid a one-size-fits-all approach and instead promote development strategies tailored to the specific realities of population shrinkage and local conditions, considering regional disparities. This study provides the following recommendations based on varying levels of shrinkage and resilience across regions:

(1) Northeast China

County towns in the northeast are experiencing severe population decline. While the NRS has recovered, its synergy with the HAS and FCC has weakened, resulting in

low coordination among resilience subsystems. The core issue is the decline caused by resource depletion and delayed industrial transformation. Recommendations are as follows: (1) As GDP's impact on local resilience diminishes, the central government should establish long-term, stable transfer payments to support pensions, unemployment benefits, and healthcare. This will help mitigate the social impact of population loss. (2) The region should reduce reliance on heavy industry and focus on sectors such as modern agriculture, cold-climate tourism, and cross-border cooperation with Russia and Mongolia to revitalize the economy. (3) Prioritize concentrating populations and activities in core county towns. Vacant land should be repurposed for ecological restoration, increasing forest cover and converting ecological burdens into green assets. This will also strengthen NRS and FCC resilience.

(2) Northwest and Southwest China

The southwestern regions of Sichuan, Chongqing, and Guizhou, along with the northwestern regions of Shaanxi, Gansu, Ningxia, Qinghai, and Xinjiang, face continuous shrinkage. These regions exhibit low SCTR levels and weak coordination among resilience subsystems. A common issue is the conflict between HAS and NRS. The following recommendations are proposed: (1) As key ecological zones, these regions should prioritize forest restoration, water quality improvement, and biodiversity protection to reverse NRS decline and enhance HSA resilience. (2) Mitigating the impact of extreme precipitation is crucial in the southwestern region. Investments should focus on resilient transportation, small river management, and flood early-warning systems. In the northwestern region, efforts should focus on water conservation infrastructure and drought management to enhance NRS and FCC subsystem coordination.

(3) North China

Shrinking county towns in North China are affected by the siphoning effect from cities like Beijing and Tianjin. Recommendations are as follows: (1) These towns should integrate into the Beijing-Tianjin-Hebei urban cluster network, leveraging enhanced planning and transportation links to become hubs for technology commercialization, agricultural products, or tourism. This can transform the siphoning effect into a positive spillover. (2) To address the negative impacts of income inequality, local governments should implement policies to narrow wealth gaps, such as providing universal public services and ensuring equitable wealth distribution. This will strengthen social resilience.

(4) Central and Eastern China

In these regions, shrinkage is more localized, with higher SCTR levels but significant internal variation. The focus should be on promoting high-quality urbanization in county towns by enhancing the living environment, public services, and local culture. This will attract rural populations and returning migrants, fostering a positive interaction between HSA and FCC subsystems.

(5) South China

The southern region leads in resilience subsystem coordination, demonstrating effective governance in balancing economic growth, urban development, and ecological protection. As a coastal and highly developed region, South China should take the lead in addressing climate risks such as typhoons and sea level rise. Investments should prioritize strengthening coastal infrastructure and exploring natural solutions, such as mangrove restoration, to ensure long-term resilience.

4.4. Limitations

This study has several limitations that warrant further investigation in future research. First, due to constraints in data availability, the current analysis lacks robust indicators to comprehensively capture the role of government governance capacity. Future research

should therefore examine how government policies shape the transformation of shrinking county towns and influence their resilience. Second, the indicators selected in this study may not fully capture all the critical dimensions of SCTR. Future research should develop a more systematic and comprehensive evaluation framework—multi-dimensional, multi-temporal, and multi-objective in nature—to more accurately reflect the dynamic evolution of resilience under population shrinkage. In addition, the identification of shrinking towns is based solely on population decline rates, thereby overlooking the economic and social dimensions inherent to the multifaceted process of urban shrinkage. Finally, this study assessed the resilience of shrinking county towns only for the period 2013–2022, without incorporating projections of future demographic change. Notably, some shrinking county towns have already experienced signs of return migration, which may generate new dynamics in local human–environment interactions. Consequently, future research should extend the observation horizon and incorporate population mobility forecasting models to provide a more comprehensive analysis of the bidirectional relationship between demographic change and resilience dynamics.

5. Conclusions

This study adopts a human–environment coupling perspective to provide a comprehensive understanding of the SCTR, underscoring its importance for advancing China's new urbanization agenda. Based on coupled human–environment perspective, we developed a multidimensional evaluation model to evaluate the spatiotemporal dynamics of SCTR in China 2013 to 2022. Furthermore, we employed a GWRF model in conjunction with SHAP to elucidate the complex relationships between SCTR and its driving factors. This approach effectively addresses challenges related to nonlinearity, spatial heterogeneity, and model interpretability in attribution analysis. The main findings are as follows:

Between 2013 and 2022, the number of shrinking county towns in China increased annually, with the most significant shrinkage observed in the Northeast, Northwest, and Southwest regions. During the study period, SCTR showed a slight upward trend. Regarding the resilience of the subsystems, the trend of HSA resilience is consistent with that of overall SCTR; FCC resilience has shown a rapid increase, while the resilience of the NRS has slightly declined. From a spatial perspective, the SCTR was markedly higher in the eastern region than in the western region, as demarcated by the Hu Line. Regarding shrinkage severity, higher levels of shrinkage corresponded to slower resilience growth and weaker coupling coordination among the subsystems. These findings indicate that population shrinkage has begun to undermine county-town resilience and disrupt the coordination of human–environment interactions in China. The attribution analysis reveals that income inequality (Gini coefficient), urbanization level, local government budgetary revenue, and NDVI represent the principal determinants shaping SCTR. Moreover, in towns undergoing severe or extreme shrinkage, population outmigration emerges as a major impediment to resilience building. Therefore, strengthening the SCTR in China requires the formulation of differentiated strategies that are responsive to regional shrinkage stages and geographical specificities, thereby facilitating high-quality county-town development and contributing to the advancement of new-type urbanization.

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References

1. Alves, D.; Barreira, A.P.; Guimarães, M.H.; Panagopoulos, T. Historical trajectories of currently shrinking Portuguese cities: A typology of urban shrinkage. *Cities* **2016**, *52*, 20–29. [CrossRef]
2. Nelle, A.; Großmann, K.; Haase, D.; Kabisch, S.; Rink, D.; Wolff, M. Urban shrinkage in Germany: An entangled web of conditions, debates and policies. *Cities* **2017**, *69*, 116–123. [CrossRef]
3. Peters, D.J.; Hamideh, S.; Zarecor, K.E.; Ghandour, M. Using entrepreneurial social infrastructure to understand smart shrinkage in small towns. *J. Rural Stud.* **2018**, *64*, 39–49. [CrossRef]
4. Martinez-Fernandez, C.; Audirac, I.; Fol, S.; Cunningham-Sabot, E. Shrinking Cities: Urban Challenges of Globalization. *Int. J. Urban Reg. Res.* **2012**, *36*, 213–225. [CrossRef]
5. Tong, Y.; Liu, W.; Li, C.; Zhang, J.; Ma, Z. Understanding patterns and multilevel influencing factors of small town shrinkage in Northeast China. *Sustain. Cities Soc.* **2021**, *68*, 102811. [CrossRef]
6. Gao, Z.; Wang, S.; Gu, J. Identification and mechanisms of regional urban shrinkage: A case study of Wuhan city in the heart of rapidly growing China. *J. Urban Plan. Dev.* **2021**, *147*, 05020033. [CrossRef]
7. Li, H.; Lo, K.; Zhang, P. Population shrinkage in resource-dependent cities in China: Processes, patterns and drivers. *Chin. Geogr. Sci.* **2020**, *30*, 1–15. [CrossRef]
8. Li, H.; Mykhnenko, V. Urban shrinkage with Chinese characteristics. *Geogr. J.* **2018**, *184*, 398–412. [CrossRef]
9. Caselli, B.; Ventura, P.; Zazzi, M. Performance-based spatial monitoring. An interpretative model for long-term shrinking medium-small Italian towns. *Sustain. Cities Soc.* **2020**, *53*, 101924. [CrossRef]
10. Long, Y.; Wu, K. Shrinking cities in a rapidly urbanizing China. *Environ. Plan. A* **2016**, *48*, 220–222. [CrossRef]
11. Zhang, X.; Zhou, S. Evolution of regional population decline and its driving factors at the county level in China. *Econ. Geogr.* **2023**, *43*, 42–51+98. [CrossRef]
12. Geng, Y.; Li, X.; Li, L.; Liu, X.; Chen, X.; Chen, J.; Cheng, J. Static-dynamic characteristics and management scheme of county space resilience based on geographical natures—An empirical study of 95 counties from Jiangsu Province, China. *Ecol. Indic.* **2024**, *166*, 112285. [CrossRef]
13. Xu, H.; Deng, H.; Zhang, D. Fine-grained sustainability assessment: County sustainable development in China from 2000 to 2017. *J. Clean. Prod.* **2023**, *425*, 138798. [CrossRef]
14. Datola, G. Implementing urban resilience in urban planning: A comprehensive framework for urban resilience evaluation. *Sustain. Cities Soc.* **2023**, *98*, 104821. [CrossRef]
15. Li, H.; Jin, X.; Liu, J.; Feng, D.; Xu, W.; Zhou, Y. Analytical framework for integrating resources, morphology, and function of rural system resilience—An empirical study of 386 villages. *J. Clean. Prod.* **2022**, *365*, 132738. [CrossRef]
16. Drewes, J.; Van Aswegen, M. Determining the vitality of urban centres. *Sustain. World* **2011**, *142*, 15.
17. Yu, T.; Leng, H.; Yuan, Q.; Yuan, Z. Spatial-temporal patterns and driving mechanism of rural vulnerability at county level: A case study of 117 counties in Heilongjiang Province, China. *J. Rural Stud.* **2025**, *113*, 103475. [CrossRef]
18. Dubeaux, S.; Cunningham Sabot, E. Maximizing the potential of vacant spaces within shrinking cities, a German approach. *Cities* **2018**, *75*, 6–11. [CrossRef]
19. Schwarz, K.; Berland, A.; Herrmann, D.L. Green, but not just? Rethinking environmental justice indicators in shrinking cities. *Sustain. Cities Soc.* **2018**, *41*, 816–821. [CrossRef]
20. Sun, Y.; Wang, Y.; Zhou, X.; Chen, W. Are shrinking populations stifling urban resilience? Evidence from 111 resource-based cities in China. *Cities* **2023**, *141*, 104458. [CrossRef]
21. Shi, B.; Liu, H.; Huang, L.; Zhang, Y.; Xiang, Z. Increasing Vulnerability of Village Heritage: Evidence from 123 Villages in Aba Prefecture, Sichuan, China. *Land* **2023**, *12*, 2048. [CrossRef]
22. Che, Y.; Zhang, Y.; Duan, W.; Zhang, B.; Chen, H. An evaluation of county resilience development levels at the provincial level utilizing multi-source data: A case study of Shandong province. *Urban Dev. Stud.* **2024**, *31*, 18–23.
23. Holling, C.S. Resilience and stability of ecological systems. *Annu. Rev. Ecol. Evol. Syst.* **1973**, *4*, 1–23. [CrossRef]
24. Walker, B.; Holling, C.S.; Carpenter, S.R.; Kinzig, A. Resilience, adaptability and transformability in social–ecological systems. *Ecol. Soc.* **2004**, *9*, 5. [CrossRef]

25. Zhao, R.; Fang, C.; Liu, J.; Zhang, L. The evaluation and obstacle analysis of urban resilience from the multidimensional perspective in Chinese cities. *Sustain. Cities Soc.* **2022**, *86*, 104160. [CrossRef]
26. Wang, H.; Ge, Q. Ecological resilience of three major urban agglomerations in China from the "environment–society" coupling perspective. *Ecol. Indic.* **2024**, *169*, 112944. [CrossRef]
27. Ji, X.; Nie, Z.; Wang, K.; Xu, M.; Fang, Y. Spatiotemporal evolution and influencing factors of urban resilience in the Yellow River Basin, China. *Reg. Sustain.* **2024**, *5*, 100159. [CrossRef]
28. Liu, R.; Zhang, L.; Tang, Y.; Jiang, Y. Understanding and evaluating the resilience of rural human settlements with a social-ecological system framework: The case of Chongqing Municipality, China. *Land Use Policy* **2024**, *136*, 106966. [CrossRef]
29. Zang, Y.; Wang, H.; Huang, J.; Liu, G.; Li, J. Community disaster resilience assessment and external association characteristics analysis based on accessibility of service facilities: From the perspective of 15-minute life circle. *Sustain. Cities Soc.* **2025**, *118*, 106051. [CrossRef]
30. Lu, H.; Lu, X.; Jiao, L.; Zhang, Y. Evaluating urban agglomeration resilience to disaster in the Yangtze Delta city group in China. *Sustain. Cities Soc.* **2022**, *76*, 103464. [CrossRef]
31. Lu, Y.; Zhai, G.; Zhai, W. Quantifying urban spatial resilience using multi-criteria decision analysis (MCDA) and back propagation neural network (BPNN). *Int. J. Disaster Risk Reduct.* **2024**, *111*, 104694. [CrossRef]
32. Band, S.S.; Qasem, S.N.; Eslami, S.; Mansor, Z.; Gupta, B.B.; Pai, H.-T.; Biyari, M.; Mosavi, A.; Sajedi Hosseini, F. Integrating the pressure-state-response model with the extension catastrophe progression for flood risk and resilience assessment. *Environ. Sustain. Indic.* **2025**, *27*, 100727. [CrossRef]
33. Yin, S.; Shi, R.; Wu, N.; Yang, J. Measuring the impact of technological innovation on urban resilience through explainable machine learning: A case study of the Yangtze River Delta region, China. *Sustain. Cities Soc.* **2025**, *127*, 106457. [CrossRef]
34. Ahmadi, Z.; Ghasemi, M.; Khavarian-Garmsir, A.R.; Ahmadi, M. Integrating flood and earthquake resilience: A framework for assessing urban community resilience against multiple hazards. *J. Saf. Sci. Resil.* **2024**, *5*, 330–343. [CrossRef]
35. Zhang, C.; Zhou, Y.; Yin, S. Interaction mechanisms of urban ecosystem resilience based on pressure-state-response framework: A case study of the Yangtze River Delta. *Ecol. Indic.* **2024**, *166*, 112263. [CrossRef]
36. Li, L.; Xu, J.; Liang, Y. The formation and evolution of vulnerability risk of rural poor groups under the perspective of social support—Based on the analysis of "sensitivity-resilience". *Heliyon* **2024**, *10*, e30305. [CrossRef]
37. Zhu, S.; Feng, H.; Arashpour, M.; Zhang, F. Enhancing urban flood resilience: A coupling coordinated evaluation and geographical factor analysis under SES-PSR framework. *Int. J. Disaster Risk Reduct.* **2024**, *101*, 104243. [CrossRef]
38. Wang, H.; Liu, Z.; Zhou, Y. Assessing urban resilience in China from the perspective of socioeconomic and ecological sustainability. *Environ. Impact Assess. Rev.* **2023**, *102*, 107163. [CrossRef]
39. Zhang, R.; Yuan, Y.; Li, H.; Hu, X. Improving the framework for analyzing community resilience to understand rural revitalization pathways in China. *J. Rural Stud.* **2022**, *94*, 287–294. [CrossRef]
40. Chen, X.-L.; Yu, L.-X.; Lin, W.-D.; Yang, F.-Q.; Li, Y.-P.; Tao, J.; Cheng, S. Urban resilience assessment from the multidimensional perspective using dynamic Bayesian network: A case study of Fujian Province, China. *Reliab. Eng. Syst. Saf.* **2023**, *238*, 109469. [CrossRef]
41. Liu, W.; Zhou, J.; Li, X.; Zheng, H.; Liu, Y. Urban resilience assessment and its spatial correlation from the multidimensional perspective: A case study of four provinces in North-South Seismic Belt, China. *Sustain. Cities Soc.* **2024**, *101*, 105109. [CrossRef]
42. Döringer, S.; Uchiyama, Y.; Penker, M.; Kohsaka, R. A meta-analysis of shrinking cities in Europe and Japan. Towards an integrative research agenda. *Eur. Plan. Stud.* **2020**, *28*, 1693–1712. [CrossRef]
43. Ortiz-Moya, F. Coping with shrinkage: Rebranding post-industrial Manchester. *Sustain. Cities Soc.* **2015**, *15*, 33–41. [CrossRef]
44. Ribant, M.; Chen, X. A typology of US shrinking cities. *Prof. Geogr.* **2020**, *72*, 152–164. [CrossRef]
45. Bernt, M.; Haase, A.; Großmann, K.; Cocks, M.; Couch, C.; Cortese, C.; Krzysztofik, R. How does (n't) Urban Shrinkage get onto the Agenda? Experiences from L eipzig, L iverpool, G enoa and B ytom. *Int. J. Urban Reg. Res.* **2014**, *38*, 1749–1766. [CrossRef]
46. Martinez-Fernandez, C.; Weyman, T.; Fol, S.; Audirac, I.; Cunningham-Sabot, E.; Wiechmann, T.; Yahagi, H. Shrinking cities in Australia, Japan, Europe and the USA: From a global process to local policy responses. *Prog. Plan.* **2016**, *105*, 1–48. [CrossRef]
47. Wolff, M.; Wiechmann, T. Urban growth and decline: Europe's shrinking cities in a comparative perspective 1990–2010. *Eur. Urban Reg. Stud.* **2018**, *25*, 122–139. [CrossRef]
48. Blanco, H.; Alberti, M.; Forsyth, A.; Krizek, K.J.; Rodríguez, D.A.; Talen, E.; Ellis, C. Hot, congested, crowded and diverse: Emerging research agendas in planning. *Prog. Plan.* **2009**, *71*, 153–205. [CrossRef]
49. Guo, Z.; Yan, L.; Zhang, Z.; Guo, J. A study on patterns and strategies of in-situ urbanization in China with county towns as key carriers. *City Plan. Rev.* **2025**, *49*, 40–48+74.
50. Martin, R.; Sunley, P.; Tyler, P. Local growth evolutions: Recession, resilience and recovery. *Camb. J. Reg. Econ. Soc.* **2015**, *8*, 141–148. [CrossRef]
51. Sutton, J.; Arcidiacono, A.; Torrisi, G.; Arku, R.N. Regional economic resilience: A scoping review. *Prog. Hum. Geogr.* **2023**, *47*, 500–532. [CrossRef]

52. Liu, Y.; Liu, Y.; Ou, C. Scientific cognition and detection methods of modern human-earth system. In Proceedings of the AGU Fall Meeting Abstracts, San Francisco, CA, USA, 11–15 December 2023; p. SY52B-01.
53. An, L. Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecol. Model.* **2012**, *229*, 25–36. [CrossRef]
54. Hyun, J.-Y.; Huang, S.-Y.; Yang, Y.-C.E.; Tidwell, V.; Macknick, J. Using a coupled agent-based modeling approach to analyze the role of risk perception in water management decisions. *Hydrol. Earth Syst. Sci.* **2019**, *23*, 2261–2278. [CrossRef]
55. Liu, J.; Dietz, T.; Carpenter, S.R.; Alberti, M.; Folke, C.; Moran, E.; Pell, A.N.; Deadman, P.; Kratz, T.; Lubchenco, J. Complexity of coupled human and natural systems. *Science* **2007**, *317*, 1513–1516. [CrossRef]
56. Yang, Y.E.; Son, K.; Hung, F.; Tidwell, V. Impact of climate change on adaptive management decisions in the face of water scarcity. *J. Hydrol.* **2020**, *588*, 125015. [CrossRef]
57. Turner, B.L.; Matson, P.A.; McCarthy, J.J.; Corell, R.W.; Christensen, L.; Eckley, N.; Hovelsrud-Broda, G.K.; Kasperson, J.X.; Kasperson, R.E.; Luers, A. Illustrating the coupled human–environment system for vulnerability analysis: Three case studies. *Proc. Natl. Acad. Sci. USA* **2003**, *100*, 8080–8085. [CrossRef]
58. Galvani, A.P.; Bauch, C.T.; Anand, M.; Singer, B.H.; Levin, S.A. Human–environment interactions in population and ecosystem health. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 14502–14506. [CrossRef]
59. Fu, B. Promoting Geography for Sustainability. *Geogr. Sustain.* **2020**, *1*, 1–7. [CrossRef]
60. Ostrom, E. A General Framework for Analyzing Sustainability of Social-Ecological Systems. *Science* **2009**, *325*, 419–422. [CrossRef] [PubMed]
61. Liu, J.; Mooney, H.; Hull, V.; Davis, S.J.; Gaskell, J.; Hertel, T.; Lubchenco, J.; Seto, K.C.; Gleick, P.; Kremen, C. Systems integration for global sustainability. *Science* **2015**, *347*, 1258832. [CrossRef]
62. Adger, W.N. Vulnerability. *Glob. Environ. Change* **2006**, *16*, 268–281. [CrossRef]
63. Gunderson, L.H.; Holling, C.S. *Panarchy: Understanding Transformations in Human and Natural Systems*; Island Press: Washington, DC, USA, 2002.
64. Turner Ii, B. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? *Glob. Environ. Change* **2010**, *20*, 570–576. [CrossRef]
65. Stokols, D.; Lejano, R.P.; Hipp, J. Enhancing the resilience of human–environment systems: A social ecological perspective. *Ecol. Soc.* **2013**, *18*, 7. [CrossRef]
66. Li, Y.; Kappas, M.; Li, Y. Exploring the coastal urban resilience and transformation of coupled human-environment systems. *J. Clean. Prod.* **2018**, *195*, 1505–1511. [CrossRef]
67. Bauch, C.T.; Sigdel, R.; Pharaon, J.; Anand, M. Early warning signals of regime shifts in coupled human–environment systems. *Proc. Natl. Acad. Sci. USA* **2016**, *113*, 14560–14567. [CrossRef]
68. Allington, G.R.; Li, W.; Brown, D.G. Urbanization and environmental policy effects on the future availability of grazing resources on the Mongolian Plateau: Modeling socio-environmental system dynamics. *Environ. Sci. Policy* **2017**, *68*, 35–46. [CrossRef]
69. Brelsford, C.; Lobo, J.; Hand, J.; Bettencourt, L.M. Heterogeneity and scale of sustainable development in cities. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 8963–8968. [CrossRef]
70. Wu, J. Landscape sustainability science: Ecosystem services and human well-being in changing landscapes. *Landsc. Ecol.* **2013**, *28*, 999–1023. [CrossRef]
71. Gurrutxaga, M. Incorporating the life-course approach into shrinking cities assessment: The uneven geographies of urban population decline. *Eur. Plan. Stud.* **2020**, *28*, 732–748. [CrossRef]
72. Rao, Y.; Wu, C.; He, Q. The antagonistic effect of urban growth pattern and shrinking cities on air quality: Based on the empirical analysis of 174 cities in China. *Sustain. Cities Soc.* **2023**, *97*, 104752. [CrossRef]
73. Zhu, C.; Fang, C.; Zhang, L. Analysis of the coupling coordinated development of the Population–Water–Ecology–Economy system in urban agglomerations and obstacle factors discrimination: A case study of the Tianshan North Slope Urban Agglomeration, China. *Sustain. Cities Soc.* **2023**, *90*, 104359. [CrossRef]
74. Ran, Z.; Gao, J.; Yang, J.; Li, C. Evolution and formation mechanism of the agglomeration pattern of commercial fitness resources in China. *Acta Geogr. Sin.* **2023**, *78*, 1573–1590.
75. Zhu, Z.; Zheng, Y.; Xiang, P. Deciphering the spatial and temporal evolution of urban anthropogenic resilience within the Yangtze River Delta urban agglomeration. *Sustain. Cities Soc.* **2023**, *88*, 104274. [CrossRef]
76. Yi, R.; Chen, Y.; Chen, A. Evaluating urban climate resilience in the Yangtze River Delta urban agglomeration: A novel method integrating the DPSIR model and Sustainable Development Goals. *J. Environ. Manag.* **2025**, *376*, 124517. [CrossRef]
77. Han, S.; Wang, B.; Ao, Y.; Bahmani, H.; Chai, B. The coupling and coordination degree of urban resilience system: A case study of the Chengdu–Chongqing urban agglomeration. *Environ. Impact Assess. Rev.* **2023**, *101*, 107145. [CrossRef]
78. Xiao, Y.; Yang, H.; Chen, L.; Huang, H.; Chang, M. Urban resilience assessment and multi-scenario simulation: A case study of three major urban agglomerations in China. *Environ. Impact Assess. Rev.* **2025**, *111*, 107734. [CrossRef]

79. Wang, J.; Shao, Z.; Zhuang, Q.; Dang, C.; Jing, P.; Cai, B.; Wang, S.; Li, J.; Yang, F.; Wang, W. Multi-scale coupling quantitative assessment of ecological-urban resilience in the Yangtze River Economic Belt. *Geo-Spat. Inf. Sci.* **2025**, 1–21. [CrossRef]
80. Pijanowski, B.C.; Brown, D.G.; Shellito, B.A.; Manik, G.A. Using neural networks and GIS to forecast land use changes: A Land Transformation Model. *Comput. Environ. Urban Syst.* **2002**, *26*, 553–575. [CrossRef]
81. Wu, D.; Zhang, Y.; Xiang, Q. Geographically weighted random forests for macro-level crash frequency prediction. *Accid. Anal. Prev.* **2024**, *194*, 107370. [CrossRef]
82. Rudin, C. Stop explaining black box machine learning models for high stakes decisions and use interpretable models instead. *Nat. Mach. Intell.* **2019**, *1*, 206–215. [CrossRef]
83. Yang, W.; Li, Y.; Liu, Y.; Fan, P.; Yue, W. Environmental factors for outdoor jogging in Beijing: Insights from using explainable spatial machine learning and massive trajectory data. *Landsc. Urban Plan.* **2024**, *243*, 104969. [CrossRef]
84. Wang, L.; Yang, J.; Wu, S.; Hu, L.; Ge, Y.; Du, Z. Enhancing mineral prospectivity mapping with geospatial artificial intelligence: A geographically neural network-weighted logistic regression approach. *Int. J. Appl. Earth Obs. Geoinf.* **2024**, *128*, 103746. [CrossRef]
85. Foroutan, E.; Hu, T.; Li, Z. Revealing key factors of heat-related illnesses using geospatial explainable AI model: A case study in Texas, USA. *Sustain. Cities Soc.* **2025**, *122*, 106243. [CrossRef]
86. Li, Z.; Yan, W. Service flow changes in multilayer networks: A framework for measuring urban disaster resilience based on availability to critical facilities. *Landsc. Urban Plan.* **2024**, *244*, 104996. [CrossRef]
87. Cao, Y.; Li, Y.; Shen, S.; Wang, W.; Peng, X.; Chen, J.; Liao, J.; Lv, X.; Liu, Y.; Ma, L.; et al. Mapping urban green equity and analysing its impacted mechanisms: A novel approach. *Sustain. Cities Soc.* **2024**, *101*, 105071. [CrossRef]
88. Ma, Y.; Xu, C.; Yang, Z. Quantifying the impact of urban blue-green spaces on humid-heat exposure risk: A case study of Nanjing's central urban area. *Ecol. Indic.* **2025**, *176*, 113708. [CrossRef]
89. Gu, T.; Zhao, H.; Yue, L.; Guo, J.; Cui, Q.; Tang, J.; Gong, Z.; Zhao, P. Attribution analysis of urban social resilience differences under rainstorm disaster impact: Insights from interpretable spatial machine learning framework. *Sustain. Cities Soc.* **2025**, *118*, 106029. [CrossRef]
90. Guo, L.; Yang, S.; Peng, Y.; Yuan, M. Examining the nonlinear effects of residential and workplace-built environments on active travel in short-distance: A random forest approach. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1969. [CrossRef]
91. Cheng, L.; De Vos, J.; Zhao, P.; Yang, M.; Witlox, F. Examining non-linear built environment effects on elderly's walking: A random forest approach. *Transp. Res. Part D Transp. Environ.* **2020**, *88*, 102552. [CrossRef]
92. Xue, F.; Yao, E. Adopting a random forest approach to model household residential relocation behavior. *Cities* **2022**, *125*, 103625. [CrossRef]
93. Li, L.; Liang, X.; Li, J.; Jiao, J. China's policy for the control of air pollution and air pollution control: An empirical research based on city-level panel data. *Ecol. Econ.* **2024**, *40*, 179–186.
94. Zhu, S.; Feng, H.; Shao, Q. Evaluating Urban Flood Resilience within the Social-Economic-Natural Complex Ecosystem: A Case Study of Cities in the Yangtze River Delta. *Land* **2023**, *12*, 1200. [CrossRef]
95. Wang, H.; Hu, Y.; Guo, Y.; Wu, Z.; Yan, D. Urban flood forecasting based on the coupling of numerical weather model and stormwater model: A case study of Zhengzhou city. *J. Hydrol. Reg. Stud.* **2022**, *39*, 100985. [CrossRef]
96. Wu, Z.; Shen, Y.; Wang, H.; Wu, M. Urban flood disaster risk evaluation based on ontology and Bayesian Network. *J. Hydrol.* **2020**, *583*, 124596. [CrossRef]
97. Rentschler, J.; Avner, P.; Marconcini, M.; Su, R.; Strano, E.; Vousdoukas, M.; Hallegatte, S. Global evidence of rapid urban growth in flood zones since 1985. *Nature* **2023**, *622*, 87–92. [CrossRef]
98. Grekousis, G.; Feng, Z.; Marakakis, I.; Lu, Y.; Wang, R. Ranking the importance of demographic, socioeconomic, and underlying health factors on US COVID-19 deaths: A geographical random forest approach. *Health Place* **2022**, *74*, 102744. [CrossRef]
99. Tong, Y.; Liu, W.; Li, C.; Rong, Y.; Zhang, J.; Yang, Y.; Yan, Q.; Gao, S.; Liu, Y. County town shrinkage in China: Identification, spatiotemporal variations and the heterogeneity of influencing factors. *J. Rural Stud.* **2022**, *95*, 350–361. [CrossRef]
100. Zhang, Y.; Ding, X.; Dong, L.; Yu, S. Research on spatiotemporal patterns and influencing factors of county-level urban shrinkage in urbanizing China. *Sustain. Cities Soc.* **2024**, *109*, 105544. [CrossRef]
101. Großmann, K.; Adams, R.-M.; Bolotova, A.; Gunko, M.; Lilius, J.; Messerschmidt, S.; Sandmann, L. Self-responsibilization, the municipality, and the state: Peripheralization shaping local initiatives in shrinking small towns. *Cities* **2024**, *150*, 105067. [CrossRef]
102. Raines, A.B. *Wandel durch (Industrie) Kultur* [Change through (industrial) culture]: Conservation and renewal in the *Ruhrgebiet*. *Plan. Perspect.* **2011**, *26*, 183–207. [CrossRef]
103. Digaetano, A.; Lawless, P. Urban Governance and Industrial Decline:Governing Structures and Policy Agendas in Birmingham and Sheffield, England, and Detroit, Michigan, 1980-1997. *Urban Aff. Rev.* **1999**, *34*, 546–577. [CrossRef]
104. Glaeser, E.L.; Gyourko, J. Urban decline and durable housing. *J. Political Econ.* **2005**, *113*, 345–375. [CrossRef]
105. Sassen, S. *The Global City: New York, London, Tokyo*; Princeton University Press: Princeton, NI, USA, 2013.
106. Scott, A.J. *Global City-Regions: Trends, Theory, Policy*; Oxford University Press: Oxford, UK, 2001.

107. Li, T.; Daams, M.N.; Sijtsma, F.J. Shrinking cities in China: A long-term metropolitan perspective. *Cities* **2025**, *158*, 105702. [CrossRef]
108. Gude, V.; Melendez, R.; Islam, M.M. Factors influencing anticipated migration patterns across metropolitan cities in the United States between 2018 and 2022. *Front. Urban Rural Plan.* **2025**, *3*, 3. [CrossRef]
109. Sun, P.; Cao, N.; Zhang, K.; Lu, M. Resilience of shrinking cities: Diagnosis of shrinking effects and research on their transmission paths. *Geogr. Res.* **2024**, *43*, 1107–1125.
110. Zheng, Y.; Xin-Lu, X.; Chen-Zhen, L.; Mou, W.; Xiao-Jia, H. Development as adaptation: Framing and measuring urban resilience in Beijing. *Adv. Clim. Change Res.* **2018**, *9*, 234–242. [CrossRef]
111. Chen, Y.; Zhu, M.; Zhou, Q.; Qiao, Y. Research on spatiotemporal differentiation and influence mechanism of urban resilience in China based on MGWR model. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1056. [CrossRef]
112. Lee, T.; Painter, M. Comprehensive local climate policy: The role of urban governance. *Urban Clim.* **2015**, *14*, 566–577. [CrossRef]
113. Beauregard, R.A. The radical break in late twentieth-century urbanization. *Area* **2006**, *38*, 218–220. [CrossRef]
114. Großmann, K.; Bontje, M.; Haase, A.; Mykhnenko, V. Shrinking cities: Notes for the further research agenda. *Cities* **2013**, *35*, 221–225. [CrossRef]
115. Hackworth, J. The limits to market-based strategies for addressing land abandonment in shrinking American cities. *Prog. Plan.* **2014**, *90*, 1–37. [CrossRef]
116. Guo, Z.-H. Local revitalization: Support from local residents. *Sustainability* **2022**, *14*, 8298. [CrossRef]
117. Glock, B.; Häußermann, H. New trends in urban development and public policy in eastern Germany: Dealing with the vacant housing problem at the local level. *Int. J. Urban Reg. Res.* **2004**, *28*, 919–929. [CrossRef]
118. Shi, T.; Yang, S.; Zhang, W.; Zhou, Q. Coupling coordination degree measurement and spatiotemporal heterogeneity between economic development and ecological environment—Empirical evidence from tropical and subtropical regions of China. *J. Clean. Prod.* **2020**, *244*, 118739. [CrossRef]
119. Ma, L.; Zhang, H.; Meng, X.; Lu, Q. Spatiotemporal heterogeneity of the ecological civilization in the Yangtze River economic belt. *Ecol. Indic.* **2025**, *177*, 113808. [CrossRef]

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Co-Creation, Co-Construction, and Co-Governance in Community Renewal: A Case Study of Civic Participation and Sustainable Mechanisms

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Abstract: This study focuses on Shanghai, a pioneer city in China's community renewal practices. In recent years, community renewal driven by civic participation has become a prominent research topic, leading to the emergence of numerous exemplary cases in Shanghai. However, field investigations revealed that many projects have experienced varying degrees of physical deterioration and a decline in spatial vitality due to insufficient maintenance, reflecting unsustainable outcomes. In response, this study examines a bottom-up community renewal project led by the research team, aiming to explore how broad civic participation can promote sustainable community renewal. A multidisciplinary approach incorporating perspectives from ecology, the humanities, economics, and sociology was used to guide citizen participation, while participatory observation methods recorded emotional shifts and maintenance behavior throughout the process. The results showed that civic participatory actions under the guidance of sustainability principles effectively enhanced citizens' sense of community identity and responsibility, thereby facilitating the sustainable upkeep and operation of community spaces. However, the study also found that bottom-up efforts alone are insufficient. Sustainable community renewal also requires top-down policy support and institutional safeguards. At the end, the paper concludes by summarizing the practical outcomes and proposing strategies and mechanisms for broader application, aiming to provide a reference for related practices and research.

Keywords: sustainability; community renewal; civic participation; community gardens; co-creation; co-construction; co-governance

1. Introduction

With the rapid advancement of the economy and large-scale urbanization, central areas of large and medium-sized cities have virtually no room left for new construction. As the fundamental unit of urban composition, communities have evolved in parallel with the broader trajectory of urban development [1]. However, as living standards continue to rise, communities are increasingly confronted with the dual pressures of limited spatial resources and the growing gap between residents' expectations for quality of life and the actual conditions of their living environments. In response, local governments across countries have introduced a series of community renewal policies aimed at combining top-down and bottom-up approaches to encourage public participation in reshaping aesthetically pleasing and vibrant community spaces. Driven by these policies, urban renewal efforts in many countries have gradually shifted from a period of large-scale demolition and reconstruction to a more refined, stock-based development model [2].

As China's largest economic and trade center, Shanghai is a high-density, compact international metropolis, with an average population density exceeding 3000 people per square kilometer [3]. The continuous influx of migrant populations has intensified the tension between population growth and limited land resources, resulting in highly compressed residential space and a severe shortage of per capita green space in public areas. Against this backdrop, how to optimize landscape quality and improve spatial functionality within limited community space has become a central concern for both the Shanghai municipal government and urban researchers. In 2016, Shanghai took the lead in launching the Walking Shanghai–Community Micro-Renewal Program [4], which adopted micro-intervention strategies to improve the spatial quality of aging communities, enhance visual appeal, and increase spatial efficiency in response to the pressures brought about by spatial constraints. This initiative explicitly addressed the need to repurpose small-scale, fragmented, and abandoned spaces within communities. At the same time, the Shanghai government also recognized the importance of civic participation in the process of community renewal and began promoting mechanisms that encourage civic participation. As a result, supported by relevant policies and guided by various organizations, Shanghai has in recent years witnessed the emergence of diverse forms of community renewal. These include the creation of community gardens and community living rooms, the painting of community murals, and the organization of community art events and so on. Such developments have positioned Shanghai as a pioneer in the field of community renewal in China. However, successful community renewal requires not only diversity in form but also sustainable mechanisms for long-term maintenance and support. Taking the community garden, a common feature in Shanghai's renewal practices, as an example, over 2000 community gardens of various types have been constructed across different districts in recent years. These gardens exhibit a wide range of organizational models and thematic expressions, reflecting the city's rich and diverse cultural identity. Nonetheless, field research indicates that many of these gardens encounter a range of practical problems after their completion, including plant withering, excessive weed growth, damaged facilities, and a general decline in spatial vitality.

Therefore, the objective of the present research is to explore how broad civic participation can address a range of unsustainable outcomes in community renewal. It focuses on three core research questions:

(1) How do we achieve the sustainable renewal of the community through a model of broad civic participation and community self-governance?

(2) Can civic participation in community renewal initiatives enhance residents' sense of identification with their community and their sense of responsibility for its maintenance?

(3) What concrete strategies and mechanisms can support the sustainable renewal of the community through civic participation?

In response to these questions, this study conducted a case analysis based on a bottom-up community garden project led by the research team. Throughout the project, the research team coordinated the joint participation of multiple stakeholders in the construction process. Under the guidance of sustainability principles, the project examined sustainable community renewal through ecological, cultural, economic, and social lenses. During the implementation phase, participatory observation methods were used to document the co-creation and co-construction processes involving residents, children, and multiple stakeholders. This approach allowed for close observation of participants' emotional and behavioral changes throughout the participation process, as well as continuous monitoring of maintenance behaviors in the late stages of the project. The results demonstrate that, under the guidance of sustainability principles, community renewal activities that encourage broad civic participation can, to some extent, promote the sustainable operation of

community spaces. These activities also enhance residents' sense of identification with their communities and increase their enthusiasm for participation. However, the long-term and healthy development of public community spaces still requires top-down policy guidance and more robust institutional safeguards. Finally, based on the project experience, this study summarizes a set of sustainable strategies and mechanisms that are applicable for broader implementation.

From a practical standpoint, this study provides low-cost, replicable, and bottom-up community renewal strategies for other cities facing spatial constraints and limited resources. It proposes top-down management mechanisms and offers recommendations for community policymakers, organizations, and practitioners to improve community governance structures. It also summarizes the mobilization pathways of citizens with diverse identities and details the renewal procedures, offering guidance for multi-stakeholder governance and the formation of bottom-up community renewal teams.

From a theoretical perspective, first, this study integrates the core concepts of sustainable development and participatory community planning to construct a conceptual framework of civic participation in sustainable community renewal, encompassing multidimensional collaborative governance across ecological, social, economic, and spiritual–cultural dimensions. Second, it extends the commonly recognized dimensions of sustainable renewal by adding the spiritual–cultural sustainability dimension, emphasizing the role of soft governance, such as identity recognition, collective belonging, and cultural continuity, in community renewal. Third, the study explores the integration of civic participation with ecological design and long-term maintenance. Existing research on strategic and institutional mechanisms primarily focuses on broader themes such as community social network building [5–8] and participatory governance [9–11]. Few studies have constructed a sustainable renewal framework from a multidimensional perspective, and sustained observation of post-renewal community space maintenance remains limited. This research, therefore, addresses the gap in understanding civic participation within the full-spectrum and full-process renewal of communities.

2. Literature Review

2.1. Core Concepts

2.1.1. Community Renewal

Community renewal originated in the 1950s in the United States in response to the need for post-war urban revitalization [12]. It gradually developed in the United Kingdom during the 1960s to address urban decline and social segregation [13]. In the contemporary context, community renewal primarily emerges in the context of urban development, shifting toward population planning and community adaptation to aging demographics. It encompasses both strategic planning of physical space and the cultivation of social infrastructure [14]. The overarching goal is to improve the community environment by integrating urban regeneration strategies with community governance, thereby guiding development toward a more systematic and enduring trajectory [15].

2.1.2. Participatory Community Renewal

Participatory community renewal emerged in the 1960s and 1970s as a response to academic critiques of the lack of democracy in traditional renewal models [16,17]. In 1969, Sherry Arnstein distinguished different forms of municipal participation in her work *A Ladder of Citizen Participation*, highlighting the insufficient degree of participation in urban planning at the time [18], which laid the foundation for participatory approaches in community building. This approach aims to improve community spaces through small-scale construction activities carried out collaboratively by individuals across different social

strata, identities, and roles within the community [19]. It promotes a shift in community renewal from a top-down model to one based on co-governance and sharing, emphasizing the role of citizens in enhancing community vitality and cohesion, while also serving as a key process through which civic identity is shaped [20]. As Habermas argued in *Communicative Reason*, the transition in community renewal from elite dominance to broad social participation shifts the focus from planning outcomes to the coordination of social relations [21,22].

2.1.3. Civic Participation in Sustainable Community Renewal

Sustainable community renewal derives from the concept of sustainable development proposed in the 1987 United Nations report Our Common Future [23]. It emphasizes the coordinated development of economic, social, and environmental dimensions within communities, representing an extension beyond traditional approaches focused solely on physical space improvement. Defined as a progressive approach integrating environmental protection, social equity, and economic vitality [24], it is result-oriented and aims to activate internal community assets, enable pluralistic governance, thereby fostering a renewal path that ensures community stability and development in both the present and the future [25,26].

The concept of civic participation in sustainable community renewal emphasized in this study builds upon the foundation of sustainable community renewal by reinforcing the practical value of public involvement in long-term maintenance. It is an integrative framework that combines key features of traditional community renewal, sustainable development, and participatory community planning [27]. In the face of challenges such as aging infrastructure, limited spatial resources, weakened social cohesion, and insufficient community capacity, single-dimensional interventions are inadequate for ensuring long-term development, and unilateral governance is often unable to address the complexities of community life. Therefore, this concept aims to highlight the role of civic engagement in driving integrated processes by incorporating strategies such as ecological restoration, participatory mechanisms, financial coordination, and policy support to foster multi-stakeholder collaboration and enhance community resilience. Compared to participatory community renewal, both emphasize civic participation but differ in origin, goals, methods, and depth of participation. The former treats participation as the goal, focusing on fairness and democracy. Civic participation in sustainable community renewal sees participation as a means to address community issues and promote long-term development through multidimensional coordination. It not only emphasizes ecological improvement and infrastructure optimization but also incorporates long-term dimensions such as social equity, cultural continuity, and economic resilience [28,29]. It further highlights the synergistic effects generated by the deep participation of diverse social groups throughout the process [30], making it a common approach in recent years of community research and practice.

2.2. Practice Review

Systematic community practices characterized by broad civic participation began in Japan in the 1960s with the emergence of community design, which later developed into the concept of community building (Machizukuri). Following the post-war phase of community planning, Japan began encouraging civic involvement in community renewal initiatives in the 1980s [31]. The Arima Fuji Park renewal project in Hyogo Prefecture, led by the team of Ryo Yamazaki, engaged residents in design and rule-making through workshops. This approach fostered both active and voluntary participation in ongoing maintenance. The spatial transformation thus also became a process of reconstructing

social relations and cultivating community self-governance [32].In contrast, since the 1990s, community renewal in the United States has placed greater emphasis on cultural expression and identity construction, as a response to the ethnic exclusion and spatial deprivation caused by traditional renewal approaches [33]. The Mission District Cultural Action, launched in San Francisco in 1995, used artistic practices to stimulate participation and cultural identity among marginalized groups [34], highlighting the role of the new genre of public art in community revitalization [35]. During the same period, the United Kingdom emphasized the integration of ecological protection and social equity into community renewal, promoting a resident-led path toward sustainable development [36]. For example, the BedZED project in London demonstrated a shift from physical transformation to integrated development involving people, the environment, and institutions through energy-efficient design and co-management by residents [37].

Participatory community practices emerged relatively late in China. In recent years, the focus has been on the parallel development of civic participation and micro-renewal. These practices have arisen in response to the scarcity of high-density urban space, emphasizing the encouragement of civic involvement through small-scale, incremental, and everyday interventions targeting micro-community spaces [38,39]. The earliest reference to resident participation in decision-making and implementation appeared in 1989, during Wu Liangyong's organic renewal project in Ju'er Hutong, Beijing. After 2014, a series of small-scale projects promoting resident participation began to appear. In 2015, the team led by Liu Yuelai gradually gained experience after facing initial challenges such as resident resistance and frequent loss of materials. They eventually established the first publicly participatory community garden in an open block in Shanghai, Chuangzhi Farm, which became a representative case of civic participation in community renewal. Since then, many cities across the country have promoted sustainable renewal concepts grounded in co-creation, co-construction, co-governance, and shared benefits, encouraging civic participation and enhancing community vitality. As a result, civic participation in community renewal has become a growing research focus, with increasing attention in recent years.

A review of relevant cases indicates that many countries have shifted from traditional community renewal toward approaches centered on civic participation and sustainable development, offering valuable references for community practices in China. China first began to make scattered attempts in high-density cities. However, because related practices and research are still at an early stage, a number of challenges remain. These include the absence of long-term operational mechanisms and a reliance on organizing entities or government agencies, which continues to hinder autonomous governance. Therefore, it is necessary to further explore how a multidimensional sustainability framework can support the development of a renewal mechanism that covers the entire process. In addition to strengthening social relations, the potential of broad civic participation to promote sustainability in ecological, cultural, spiritual, and economic dimensions also requires closer examination. This addresses existing gaps in the establishment of long-term operational mechanisms for community spaces and in understanding the role of civic participation throughout the renewal process.

3. Materials and Methods

3.1. Method

This study is a case study based on the front-yard renovation project of the No. 580 community in Yangpu District, Shanghai, which was initiated and led by the research team. It aimed to examine how long-term sustainable renewal of community space could be achieved through a bottom-up model of civic participation and to summarize corresponding strategies and mechanisms. The project was also used to test whether

citizens' sense of community identity and responsibility could be enhanced through actual participation.

Before the project began, a multidisciplinary approach was adopted to review relevant literature and analyze comparable cases. The review indicated that sustainable community renewal involves factors such as natural ecology, economic development, social systems, cultural advancement, and the political environment. Grounded in the concept of sustainability [40,41], the research approaches community renewal through four key dimensions: ecological, economic, social, and an expanded dimension of spiritual–cultural sustainability. This additional dimension aims to preserve and co-create shared values, collective memory, and community identity through participatory cultural practices (Figure 1).

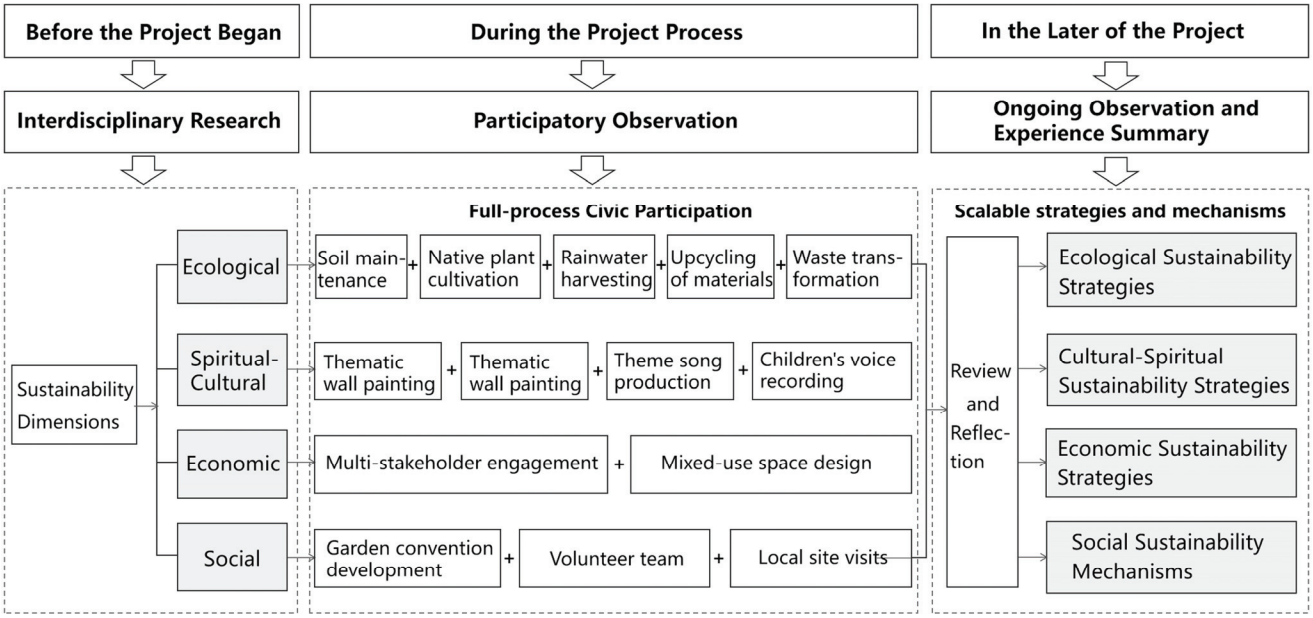

Figure 1. Research methodology framework.

During the project process, participatory observation methods were employed to observe participants' emotions, behaviors, and attitudes. The research team members participated as both participants and observers. Participatory observation originates from early 20th-century research in social anthropology and sociology. It was first applied in Bronisław Malinowski's fieldwork in the Trobriand Islands [42]. The method was later formalized by Lindeman (1924), who categorized observers in social science research as either objective observers or participant observers [43]. Participatory observation refers to the researcher immersing themselves in a specific social setting or group to observe participants' behaviors, interactions, and practices [44]. This approach allows the researcher to uncover implicit or hidden information that cannot be accessed through external interviews alone. It is particularly valuable for research aimed at understanding the lived experiences of individuals or groups within specific social contexts. This method was used to assess whether, under the guidance of sustainability principles, promoting broad-based civic participation in co-creation and co-construction could enhance residents' sense of identification with the community, increase their enthusiasm for participation, and revitalize the space, ultimately contributing to the sustainable development of community environments

In the later stages of the project, continued attention was paid to the post-construction maintenance of the community garden in order to assess both its sustainability and the challenges that emerged. The relationship between participants' frequency of activity and the condition of garden maintenance was monitored to evaluate how the level of civic engagement influenced the outcomes of community renewal. Based on observations

from the project process and the resulting findings, the study concludes by summarizing practical insights and proposing strategies and mechanisms that may serve as references for future community renewal initiatives.

3.2. Site Description

This community renewal project was conducted in Shanghai, China. As the first city in the country to implement community micro-renewal practices, Shanghai has accumulated extensive experience in promoting bottom-up civic self-governance and has garnered considerable popular support. The site was a small green space located at the entrance of the Friendly Neighbors Gate (Figure 2), in front of Lane 580 in Yangpu District. The Friendly Neighbors Gate is a small symbolic gate opened in the shared wall between an old residential compound at Lane 580 in Yangpu District, Shanghai, and the newly developed Chuangzhi Fang community, representing neighborly friendliness and community integration. Its opening enabled full access to surrounding public service resources, reduced service delivery costs, and became a representative case of open community development. The neighborhood surrounding the Friendly Neighbors Gate was among the earliest sites in Shanghai to carry out community renewal experiments. Residents in the area have accumulated practical experience in community building and have actively participated in relevant initiatives, which contributed to the effective implementation of this project.



Figure 2. Photo of the Friendly Neighbors Gate.

The project focused on the utilization of micro-scale spaces within the community. The selected site covered an area of approximately 20 m^2. The surrounding area benefits from convenient transportation, a diverse commercial landscape, and the presence of two kindergartens nearby (Figure 3). Prior to the renewal, the site featured a monotonous plant landscape with exposed bare soil, poor visual appeal, and was inaccessible to residents. Based on feedback collected from local residents, the renewal aimed to enhance the site's visual aesthetics, increase plant diversity, and serve an informational and communicative function for the community.

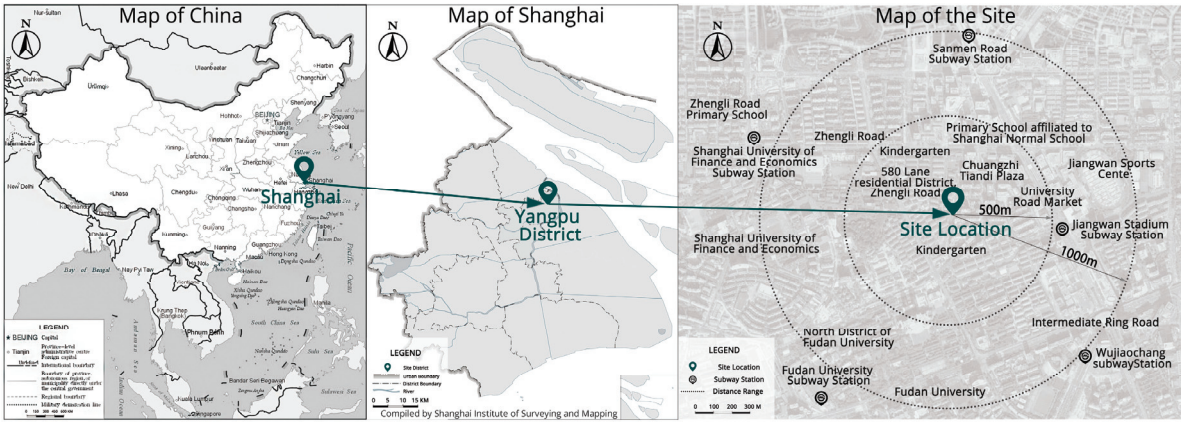

Figure 3. Site location and surrounding situation map.

4. Practice Process

Before the project began, site research was conducted, relevant stakeholders such as the community committee, residents, volunteers, and other interested parties were contacted and recruited, and a renewal team was established. Multiple stakeholders were brought together to participate in the decision-making process, with an intentional effort to diminish the dominance of the professional team and to transfer decision-making power to all participants. Through a series of co-creation meetings and material collection initiatives, the process sought to strengthen participants' sense of involvement and responsibility. During the co-construction phase, the organizing team focused on guiding the process according to the core design objectives and the four dimensions of sustainability, while allowing the final outcome of the site construction to be shaped by the participants themselves. Meanwhile, participants and long-term volunteers were recruited through multiple channels during the co-creation and co-construction stages to lay the foundation for ongoing maintenance (Figure 4).

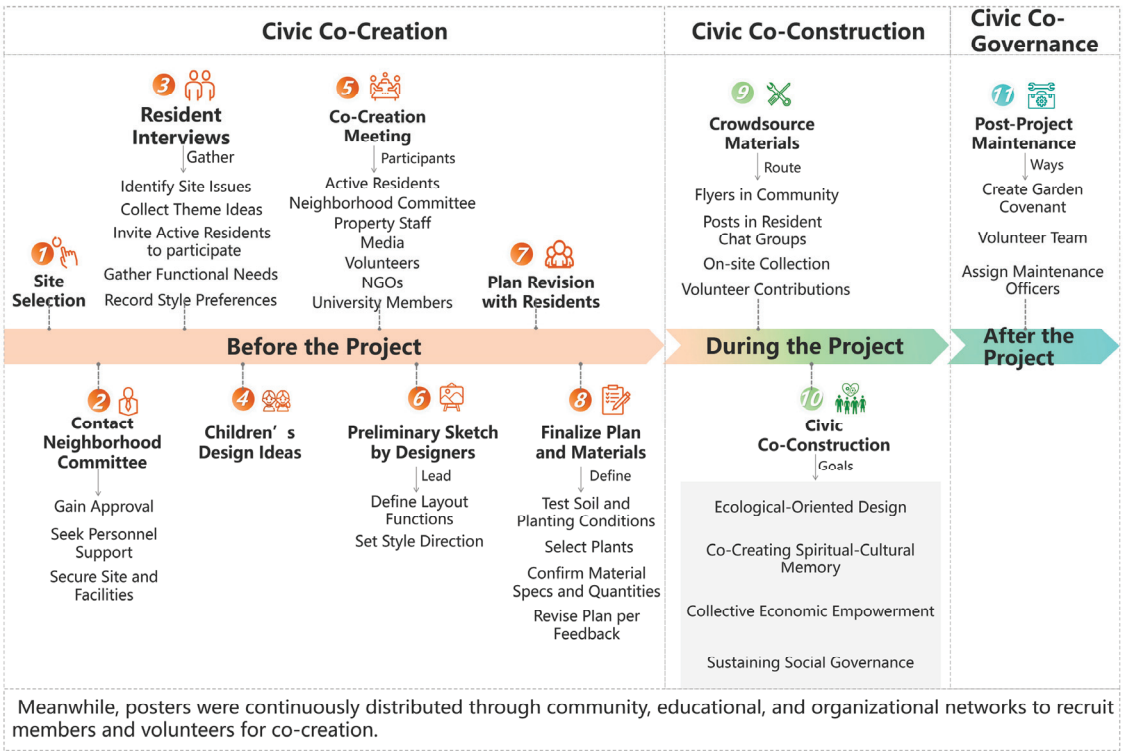

Figure 4. Project process diagram.

4.1. Ecological-Oriented Design

The project adopted an ecological design approach, focusing on the creation of the physical space through soil restoration (Figure 5), the planting of native vegetation, rainwater collection, and the reuse of discarded materials (Figure 6). The process began with pH testing of the original soil, followed by composting and the incorporation of nutrient-rich soil. Native plant species that were well-suited to the site conditions were selected to reduce long-term maintenance costs. At the same time, the ecological characteristics of the plants were fully utilized; for instance, ophiopogon japonicus, a water-loving species, was planted in elevated areas to naturally absorb rainwater runoff, avoiding the need for impermeable hardscape materials and restoring the natural water cycle on site. In addition, all artistic installations and rainwater collection devices within the site were made from discarded or recycled materials. These elements followed the principles of waste reduction, reuse, and recyclability, laying an ecological foundation for the site's long-term sustainable development. By applying ecological design concepts within the context of a micro-scale community space, the site underwent a comprehensive transformation in both appearance and function (Figure 7).



Figure 5. Plant removal and soil composting on site.



Figure 6. Upcycling of discarded materials.

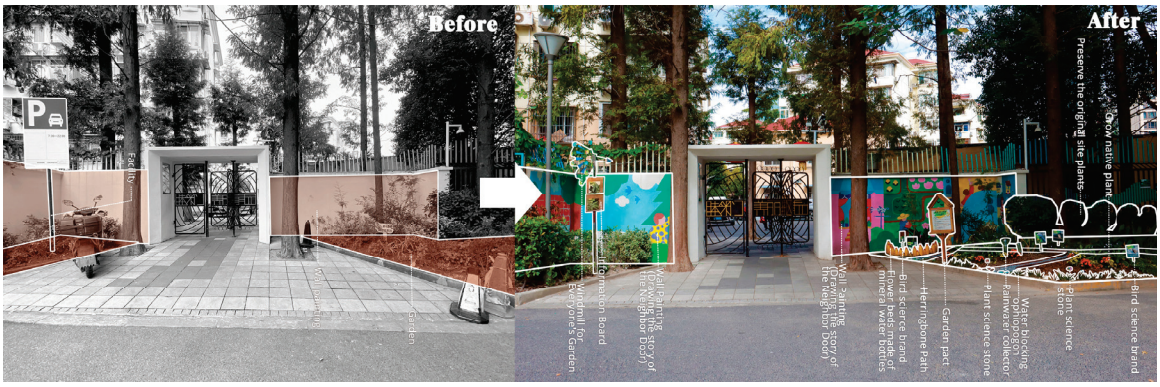

Figure 7. Before-and-after comparison of the site.

4.2. Co-Creating Spiritual–Cultural Memory

This project adhered to the principle of broad civic participation, emphasizing the empowerment of residents, volunteers, and diverse community groups. Through processes of co-creation and co-construction, it aimed to promote both spatial and cultural renewal. During implementation, the research team actively invited teachers and children from nearby kindergartens to participate in the design and production of plant science signs and the creation of community murals (Figures 8 and 9). The team also supported the children in recording audio guides for plant knowledge dissemination (Figure 10). By turning children's recordings into QR codes and combining them with plant images to create display plaques, basic scientific knowledge is integrated into daily life in an engaging and publicly accessible form, serving as part of children's foundational science learning. At the same time, elderly residents from the community were invited to provide suggestions on plant selection, and a retired painter contributed to the mural's creation. These intergenerational dialogues and the transmission of local knowledge helped strengthen the intersection between cultural heritage and community identity. The mural's theme was artistically reimagined based on the historical evolution of the Friendly Neighbors Gate, transforming the community's collective memory into a visual expression of local culture.



Figure 8. Teachers and children from nearby kindergartens discuss garden renewal details.



Figure 9. Children, parents and teachers collaboratively painting murals and educational cobblestones.



Figure 10. Educational plant signage with children's audio recordings (QR code scannable).

As the project progressed, community members gradually shifted from passive participants to active cultural producers. Resident volunteers actively proposed naming the garden, hoping it would have an identity of its own. It was eventually named "Everyone's Garden" to reflect the spirit of collective participation and co-creation. An enthusiastic resident composed a theme song for the garden and organized local children to record it together. Elderly residents voluntarily wrote poems for the garden, and student volunteers who participated in the co-creation documented their experience in diaries. Through music, literature, and other creative forms, residents collaboratively constructed and preserved the community's shared cultural memory. This process not only demonstrated the localized and public nature of cultural production but also laid the foundation for building a spiritually connected and resident-centered cultural community.

4.3. Collective Economic Empowerment

From an economic perspective, this community renewal considered both multi-stakeholder participation and diversified commercial models. First, it brought together a wide range of stakeholders, including neighborhood committees, residents, property management teams, volunteers, designers, university faculty and students, media, and social organizations, to engage in co-creation and co-construction (Figures 11 and 12).

Materials required during the renewal process were partially donated by the co-creators, while some were provided by property managers, nearby schools, and residents. Certain plants were acquired through a resource-exchange mechanism with community members, and the remaining supplies were funded by social organizations (Table 1). The involvement of multiple stakeholders helped to ease financial burdens while integrating diverse identities and resources, ultimately providing the community with broader forms of support and assurance.

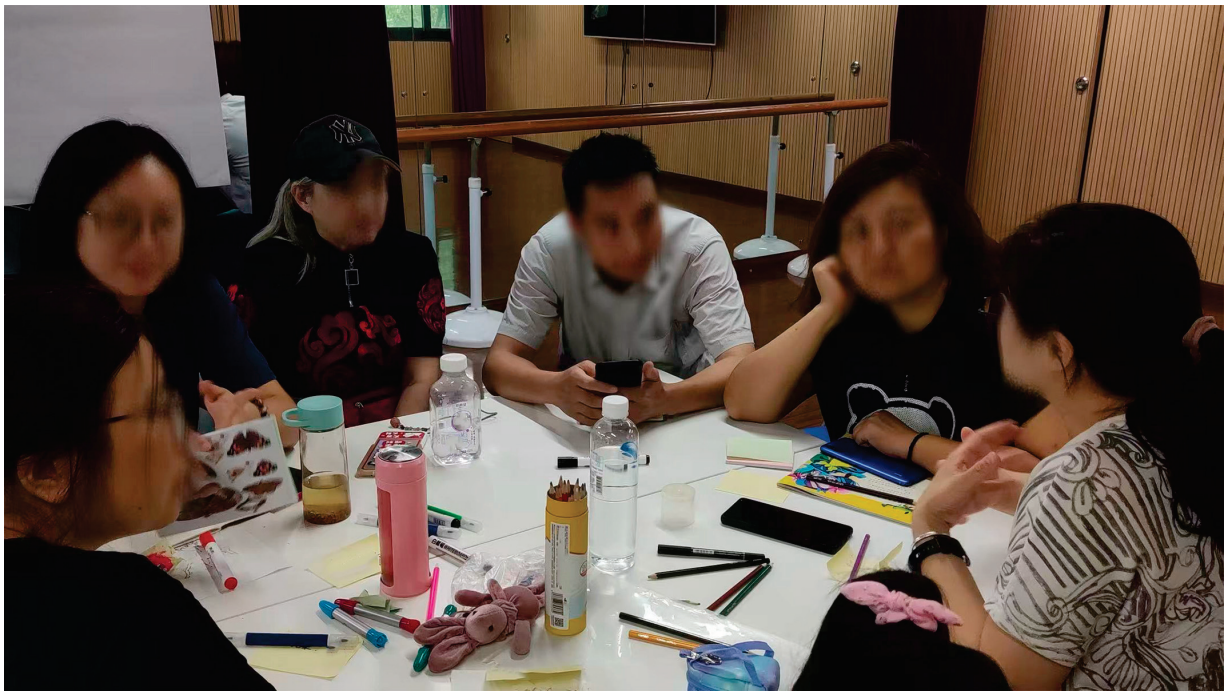

Figure 11. Multiple stakeholders jointly discussing renewal strategies for the site.

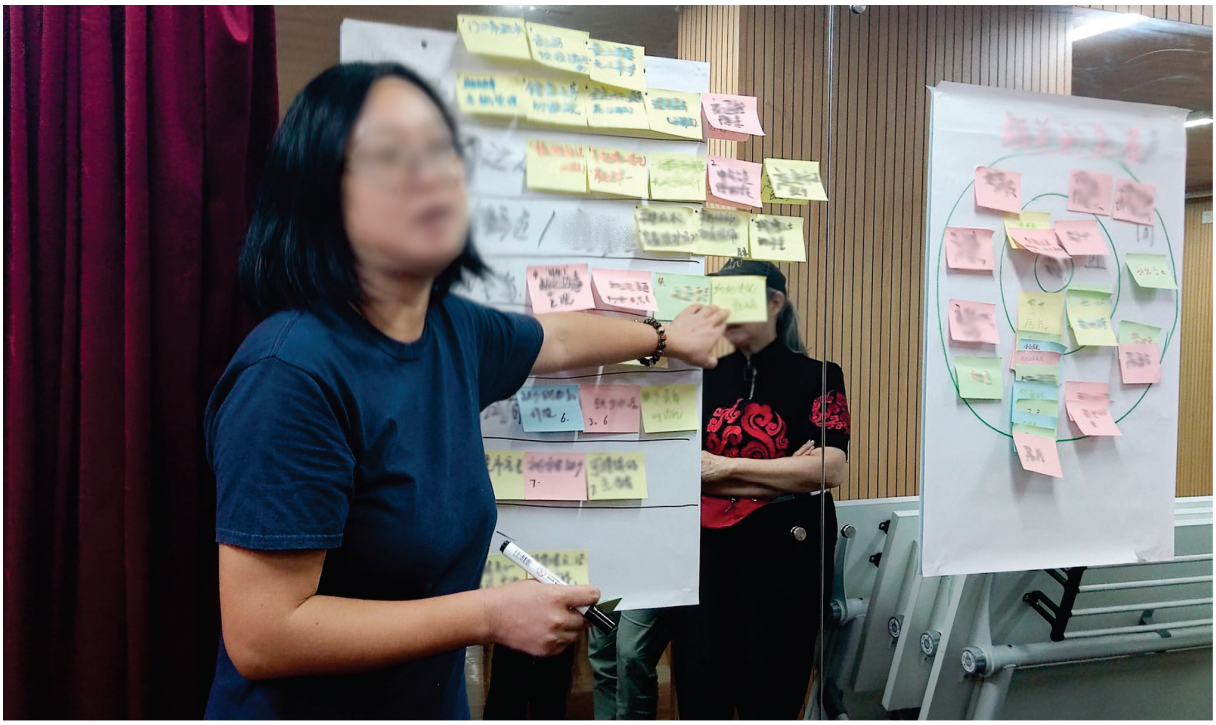

Figure 12. A photo of team members discussing the proposal on-site.

Table 1. Material list and expenditure details during the renewal process.

Category	Item	Quantity	Cost (CNY)	Acquisition Method
Tools	Shovels, spades, hot melt gun	Several	0	Borrowed from social organization and kindergarten
	Nails, hammers, electric drill, electric screwdriver	Several	0	Borrowed from property management
Materials	Crushed gravel	150 kg	300	Provided by property management, sponsored by volunteers
	Cobblestones	25 pcs	0	Provided by property management
	Used beverage bottles	Several	0	Provided by property management and children
	Discarded wooden boards	Several	0	Provided by property management
	Wall paint and painting tools	Several	84	Purchased by self and donated by residents
	Decorative ceramic pots	2	0	Donated by residents
	Spray paint, wood preservative	4	65	Purchased
	Lawn lights	4	72	
	Rainwater infiltration tools	10	8	
	Acrylic panels	2	30	
	Children's science signs	8	40	
	Iron wire	10 m	30	
	Information board	1	0	Donated by the kindergarten
Plants	Tree bark	2 bags	0	Provided by property management
	Begonia cucullata	7	0	Replanted from the original site
	Euonymus japonicus, *Euonymus grandiflorus*	Several	0	
	Photinia	6	0	
	Ligustrum	Several	0	
	Pittosporum tobira	2	0	
	Coleus blumei	6	0	
	Asparagus setaceus	1	0	
	Aspidistra elatior Blume	8	0	
	Vinca major	Several	0	
	Aucuba japonica	Several	0	
	Sansevieria trifasciata	2	0	Exchanged with residents
	Monstera deliciosa	1	0	
	Ilex spp.	Several	0	Donated by volunteers
	Kalanchoe blossfeldiana	20	0	Donated by a social organization
	Ophiopogon japonicus	Several		
	Pteris vittata	Several	0	
	Nephrolepis cordifolia	Several	0	
	Rhododendron spp.	4	0	
	Total		629	

In terms of diversified commercial design, the project capitalized on Shanghai's open-minded urban culture and dynamic atmosphere to establish cooperative relationships with surrounding businesses. These partnerships facilitated mutual promotion by offering commercial actors access to on-site publicity space, thereby enhancing visibility for both parties. Taking advantage of the site's strategic location, the project was linked with vibrant adjacent streets to host community exhibitions, publicity campaigns, and information-sharing activities. Moreover, leveraging the close relationship with the Friendly Neighbors Gate community center, the team collaborated with government departments and social organizations to organize a community visit. These activities served as grassroots publicity platforms for community renewal and helped generate sustained economic benefits from multiple sources.

4.4. Sustaining Social Governance

In the later stages of the project, the project team explored sustainable maintenance strategies from the perspectives of social institutions and public governance, aiming to ensure the long-term continuity of community co-construction outcomes. First, a community garden covenant was established to regulate the behavior of passersby, maintain order in daily use, and reinforce both residents' and visitors' awareness of responsibility and norms regarding shared spaces.

Second, a post-maintenance team was formed, composed of local residents and volunteers. A duty schedule and clear division of responsibilities were established to support collaborative and self-organized maintenance at the institutional level. This mechanism proved effective during the early phase of implementation. Specifically, the volunteer team was able to carry out routine maintenance and safety inspections at short intervals, which helped preserve the garden's cleanliness and functionality. However, long-term observations revealed that relying solely on a rotating volunteer force was insufficient to support high-frequency, continuous maintenance. This highlighted the need to introduce more stable management personnel or institutionalized operational mechanisms, facilitating continuous maintenance.

In addition, the project team intentionally integrated the garden into local tours, exhibitions, and public cultural activities, thereby transforming it from a small green space in front of residents' homes into a public display platform with communicative cultural value. This strategy not only enhanced the garden's public visibility and external attention but also activated residents' sense of care for public resources through a mechanism of social supervision. As a result, it provided support for the site's autonomous and sustainable operation.

5. Results

5.1. Analysis of Participants

5.1.1. Participant Proportion

A total of 139 individuals participated in the project. Among them, residents, volunteers, and organized groups of children and students from kindergartens and primary or secondary schools formed the core participants, accounting for 74.11% of the total. In terms of age distribution, individuals under the age of 18 and those aged 41–50 constituted the majority, making up 56.11% of participants (Table 2). This pattern is often attributed to the tendency of parents to bring their children to such community activities in hopes of enhancing their children's experience with social practice and civic awareness. Participation among young adults aged 19–30 was relatively low. This is likely due to the public nature of community activities, which offer limited personal gain and demand private time, making such initiatives less appealing to this age group. However, the renewal and devel-

opment of communities often rely on the energy and creativity of young people. Based on these findings, future community renewal efforts may consider several approaches to enhance sustainability: increasing child-oriented programs to attract parents and educators; expanding the scope of elder-support initiatives; cultivating a youth-friendly community environment to encourage the involvement of young adults.

Table 2. Summary of the proportion of participants.

Items	Index	Frequency	Percentage	Cumulative Percentage
Age	Under 18	46	33.09	33.09
	19–25	11	7.90	40.99
	26–30	8	5.76	46.75
	31–40	25	17.99	64.74
	41–50	32	23.02	87.76
	51–60	9	6.48	94.24
	Above 60	8	5.76	100.00
Identity	Residents within the community	25	17.99	17.99
	Nearby residents	8	5.76	23.75
	Community service staff	12	8.63	32.38
	University faculty and students	8	5.76	38.14
	Designers	4	2.88	41.02
	Volunteers	24	17.27	58.29
	Kindergarten children and primary/secondary school students	46	33.09	91.38
	Members of social organizations	10	7.19	98.57
	Company employees	2	1.43	100.00
Gender	Male	50	35.97	35.97
	Female	89	64.03	100.00
	Total	139	100.00	100.00

5.1.2. Participant Composition at Different Stages

Through the observation of participants across different stages of the project, it was found that levels of engagement varied significantly among different age groups and identity categories (Table 3). During the initial co-creation phase, participation was primarily concentrated among community residents, volunteers, and members of social organizations aged 31 to 50, with occasional involvement from a few older, enthusiastic residents. Participation at this stage was mainly driven by neighbor-to-neighbor engagement and individual initiative. The 31–50 age group generally demonstrated strong communication, organizational, and empathetic abilities, making them a key target for early recruitment. In addition, older residents tended to have a deeper understanding of the community and neighbor relations, along with more flexible schedules. With referrals from community committees, they could serve as catalysts within the initial team, encouraging nearby residents to engage through localized interactions.

In the mid-stage co-construction phase, in addition to community residents, volunteers, and social organizations, participation expanded to include organized groups of primary and secondary school students, as well as young children accompanied by families. Some local residents also participated temporarily after being drawn in by the co-construction activities. This stage was characterized by a combination of group-based participation organized through families and schools, and on-site recruitment of local passersby. Compared to the earlier stage, the mid-stage saw an increase in underage participants involved through family or school groups, as well as temporary local participants, alongside a relatively stable core team from the initial phase.

In the post-stage maintenance phase, participants were mainly older community residents, members of social organizations, and maintenance staff, primarily aged between 41–50 and over 60. This stage was marked by the involvement of social organizations, coordination by community committees, and individual maintenance efforts. These participants generally showed a strong sense of responsibility and long-term engagement in community affairs, making them the core force in site maintenance and a key group to involve during the post-construction phase.

Table 3. Key Participant Groups at Different Stages.

Category	Initial Stage (Co-Creation)	Middle Stage (Co-Construction)	Post Stage (Co-Governance)
Participant Roles	Residents, volunteers, designers, university students, NGO	Volunteers, residents, children, primary and secondary school students, property managers, designers, NGO	Residents, NGO, neighborhood committees, property managers
Age	41–50; 31–40	Under 18; 41–50; 31–40	Over 60; 41–50; 31–40
Group Affiliation	Individuals, neighborhood-based	Families, schools, neighborhood-based	Social organizations, community service teams, individuals, schools

This analysis provides concrete evidence for personnel integration across the early, middle, and later stages of bottom-up community renewal projects. By identifying the characteristics of key participant groups at each stage, targeted strategies for organization and engagement can be developed to ensure sustained human support. This enables a closed-loop participation model, transitioning from initial localized mobilization to multi-party coordination in the mid-stage and, finally, to ongoing maintenance.

5.1.3. Value Characteristics of Different Groups

According to the frequency of contributions made by participants (Figure 13), community members, including neighborhood committees, residents, and property management units, mainly provided site access, funding, and labor support. This highlights their fundamental role in mobilizing internal resources and advancing project implementation. Public participants, such as university researchers, designers, media professionals, volunteers, and primary and secondary school teachers and students, contributed design concepts, expert advice, service support, and promotional outreach. These contributions provided knowledge and communication resources, such as maintenance expertise, planting conditions, and renewal strategies, that enhanced both the project's technical quality and public visibility. Commercial actors, including businesses and social organizations, supported the renewal through material contributions, co-creation efforts, and experience sharing, serving as an important complement through cross-sector collaboration. These contributions spanned both tangible and intangible forms of value, underscoring the advantages of a multi-stakeholder collaborative governance model.

5.2. Analysis of Behavioral and Emotional Changes Among Participants

5.2.1. Changes in Participant Emotions and Motivation

Observations of participants' emotional and motivational changes during the project (Table 4) indicate that repeated involvement in community co-creation and co-construction activities led participants to develop a spontaneous sense of care for the site and fostered friendlier interactions among members. When inclusive participation and indi-

vidual empowerment were encouraged, participants showed higher levels of initiative and enthusiasm.

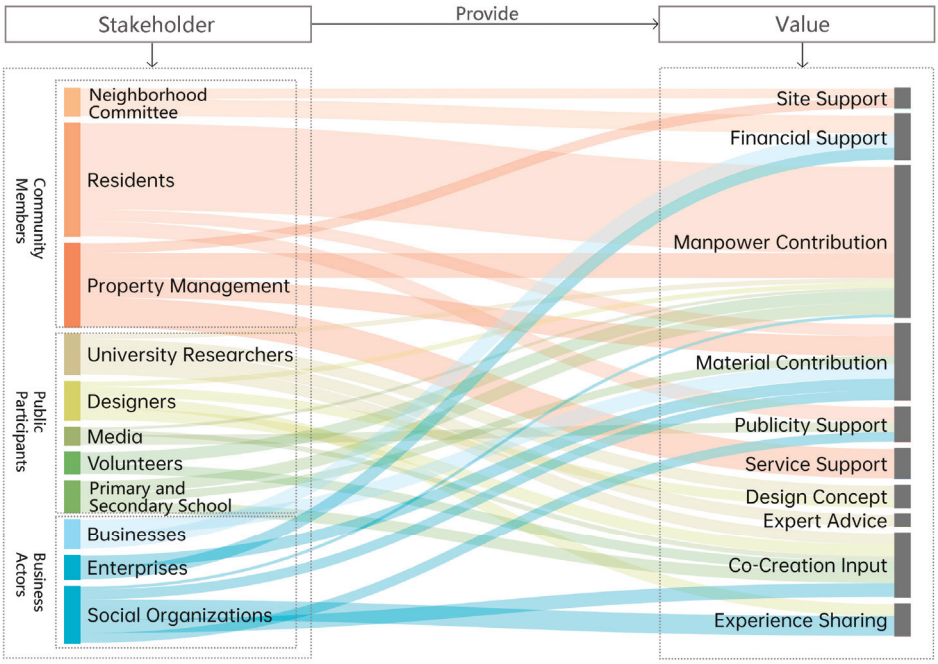

Figure 13. The actual value provided by stakeholders during the project.

Table 4. Observation summary of key participant activities.

Status	No.	Participation Content	Emotional Change	
			Before Participation	After Participation
Community Resident (A)	A1	Participated in the whole process	Actively engaged	Feels proud and gratified, and actively explains the garden's construction process and design concepts to passersby
	A2	Installation design and creation	Invited to create an art installation	Frequently introduces the art installations created
	A3	Wall painting, soil renovation	Somewhat indifferent, only accompanied the child for mural painting	Often asks if help is needed and spontaneously composes a children's song for the garden, gathering community children to record it
	A4	Assisted in wall painting design	Somewhat indifferent	Actively guides children in mural painting
	A5	Painted murals	Shy and curious	Immediately comes after school to paint murals and stones, and makes several good friends
	A6	Participated in co-creation	Apathetic	Proactively brings unused household items for upcycling
Community Service Staff (B)	B7	Provision of tools	Provided materials only, did not participate in discussions or co-creation	Actively contributes ideas for garden construction
	B8	Provided tools and materials, assisted in facility creation	Passive, uneasy	Helps with all facilities and actively searches for reusable materials

Table 4. *Cont.*

Status	No.	Participation Content	Emotional Change	
			Before Participation	**After Participation**
Nearby Resident (C)	C9	Maintenance of facilities and site	Curious but did not participate	Actively manages improperly parked bicycles near the garden and maintains the site
	C10	Created educational boards for plants and animals	Moderately enthusiastic, with average involvement	Regularly organizes kindergarten children from nearby to water the garden and clean up trash
Volunteer (D)	D11	Fully participated, leading coordination	Felt pressured and unsure of success	Feels both delighted and worried, like watching a child grow up, and is eager to ensure proper maintenance of the garden
	D12	Fully involved in design planning and co-creation	Actively participated	Fully participated and sponsored some materials
	D13	Designed and painted murals	Actively participated	Comes every day
	D14	Painted murals, participated in garden co-creation	Curious	Feels a strong sense of accomplishment and records it in a diary
College Student (E)	E15	Fully engaged in design planning and co-creation	Fairly active	Actively participates and applies the experience to other practical projects
	E16	Frequently participated in design planning and co-creation	Generally active	Actively participates and meticulously documents the co-creation experience and outcomes.
Social organization personnel (F)	F17	Planted and maintained garden plants	Almost fully involved	Very attentive to the garden's maintenance, frequently waters and fertilizes, and relocates dying plants to more fertile soil, replanting them after they revive
Journalist (G)	G18	Documented the co-creation process	Only documented the co-creation process with a camera	Participates in garden construction with two sons and produced a free documentary on the community garden

The diagram of emotional changes among primary participants (Figure 14) visually illustrates the emotional shifts before and after participation. Longer lines represent greater changes in emotional dimensions, while shorter lines indicate smaller changes. The direction of the arrows shows the direction of emotional change, and a higher position of the post-participation point reflects a higher level of motivation. The diagram shows that community renewal activities had a relatively small emotional impact on volunteers who were already highly engaged before participation. In contrast, the emotional impact was more significant among community residents and service personnel. Their attitudes shifted from initial indifference to active involvement in offering help and suggestions, accompanied by a gradual increase in the number of participants. This clearly reflects an overall rise in motivation.

This phenomenon suggests that many community members initially adopt a bystander attitude, often believing the project is "not my business." However, whether through active

or passive participation, once they engage even once, they tend to develop a positive emotional connection to the space. This sense of emotional attachment further enhances their sense of responsibility for the community space, laying a foundation for continued participation and the building of community relationships. These findings demonstrate that offering low-barrier participation opportunities and appropriate incentive mechanisms can effectively foster residents' emotional identification.

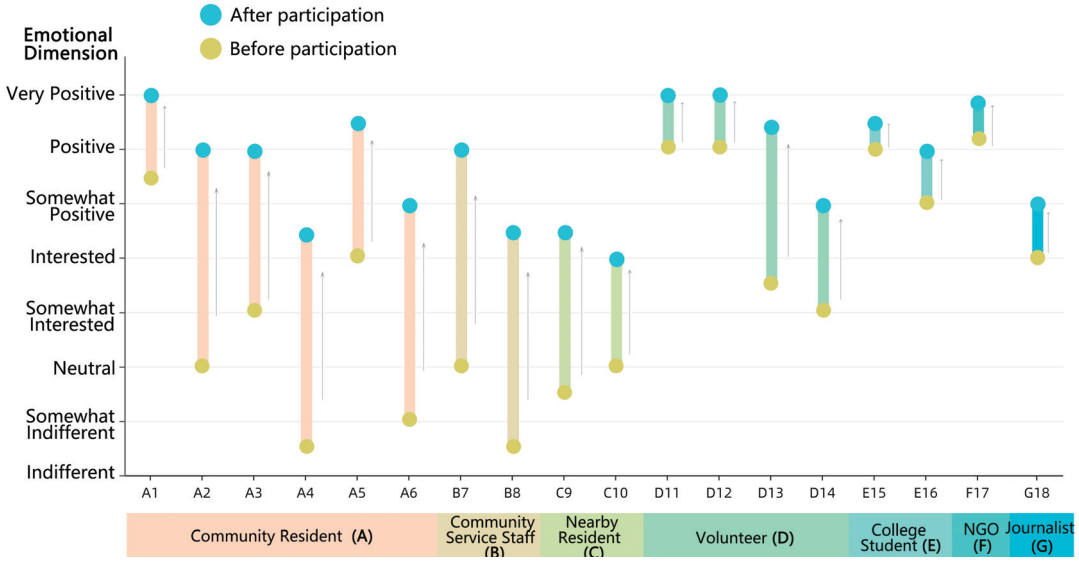

Figure 14. Diagram of emotional dimension changes among primary participants.

5.2.2. Identity Recognition Among Participants

Field observations revealed that residents who participated in community co-construction showed higher levels of site recognition and evaluation, as well as a stronger sense of responsibility for maintenance, compared to those who did not participate. This suggests that participation not only strengthened residents' emotional connection to the space but also enhanced their self-identification with the community.

According to the social identity theory proposed by Henri Tajfel and others, individuals of different ages and social roles tend to develop a sense of self-identity through the formation of group belonging when participating in shared activities [45]. Community activities can function both as a site where identity is formed and as a medium that reinforces it. When residents engage in such activities, the experience of being seen and needed can foster a sense of self-worth. This sense of self then becomes projected onto the community environment, generating a subjective feeling of "I am part of this community." This strengthens collective bonds among residents, enhances social interaction, and contributes to the formation of community identity.

Participant feedback confirmed this dynamic:

- Participant 1: "I just feel the garden looks great no matter what—probably because I helped build it. I still come by often to water the plants and clean up a bit."
- Participant 2: "My daughter helped paint the mural. Every time we pass by, she proudly tells others she helped paint this. If there's another activity like this, I'll definitely bring her again."
- Participant 3: "I often ask people passing by, 'Do you think our garden looks nice?' They always say it's beautiful, much better than before. That makes me feel proud and happy."

However, further analysis showed variation in participation behaviors among different groups (Table 5), indicating that identity recognition forms through different path-

ways. Family groups primarily build group identity through parent–child collaboration. Middle-aged individuals tend to develop value-based identity through self-expression. Adolescents often form social identity via school-based groups, while older adults achieve identity recognition through cultural memory and heritage. Recognizing these differentiated patterns can inform future community renewal design, allowing for more accurate alignment of psychological motivations and participation methods across diverse groups. This, in turn, can support a virtuous cycle of identity formation, emotional belonging, and community governance.

Table 5. Pathways of identity recognition across different groups.

Group Category	Pathways to Identity Recognition	Types of Identity Recognition	Activity Type	Observed Behavior
Family groups	Parent–child collaboration	Group Identity	Mural painting, planting	Parents and children participate together; frequent, sustained interaction
Middle-aged individuals	Self-expression	Value Identity	Design proposals, coordination, construction, idea-sharing, experience-sharing	Actively express opinions, take on tasks, work independently, communicate design intent
Adolescent students	Group belonging	Social Identity	School-organized and team projects	Higher efficiency when participating as school groups; often seek recognition or rewards
Older adults	Cultural heritage	Memory-based Identity	Storytelling, upcycling, skill-sharing	Willing to share experiences and community history

5.2.3. High-Participation Activities

During the community co-construction, the research team observed public engagement across different types of activities. It was found that activities with artistic qualities and broad accessibility, such as wall painting, plant cultivation, sound collection and recording, and the creation of art installations, generally attracted higher levels of participation. These activities were especially popular among children, families, and residents across all age groups (Table 6). In contrast, activities with strong technical requirements, such as construction or equipment installation, saw lower levels of public participation.

Table 6. Public art activities with high levels of civic participation.

No.	Activity Name	Artistic Characteristics	Mobilization Method	Primary Participant Groups
1	Wall Mural Creation	Visual arts and cultural expression	Encouraged participation	Children
2	Planting Activities	Ecological aesthetics and everyday art	Volunteer recruitment	All age groups
3	Music Recording	Sound art and resident interaction	Organized by residents	Children, parents, residents
4	Art Installation Making	Spatial aesthetics and participatory experience	Team-led facilitation	All age groups

These high-participation activities were generally organized in an open format and shared several common characteristics: (1) they were easy to access and informal in style, allowing participants to engage without high skill barriers; (2) they offered space for creativity, enabling individuals to express personal ideas and imagination, which generated

enjoyment and a sense of accomplishment; (3) they involved a high degree of interaction, facilitating interpersonal connection through collaborative processes. In such settings, residents were more likely to engage deeply and form cooperative relationships, with emotional bonds developing in the process. In particular, in parent–child and intergenerational collaboration contexts, artistic activities served not only as a medium for emotional connection but also as a trigger for identity formation.

Therefore, in community renewal practice, it is beneficial to intentionally design activities that combine artistic value, openness, and collaboration. These formats can serve as effective means to stimulate participation, enhance emotional identification, and foster a sense of belonging.

5.3. Long-Term Observations and Analysis of Sustainability

Following the conclusion of the project, a 16-month period of sustained observation was conducted, alongside a tracking study of participants' online engagement levels (Figure 15). By analyzing the site's maintenance conditions across different time periods in relation to the frequency of messages within the project's online communication group, it was found that site maintenance and online communication frequency fluctuated in parallel at multiple time nodes. During site updates or when re-maintenance occurred under the intervention of community committees or the government, participants' online activity levels increased. This indicates that community renewal actions can, to some extent, promote interaction among participants.

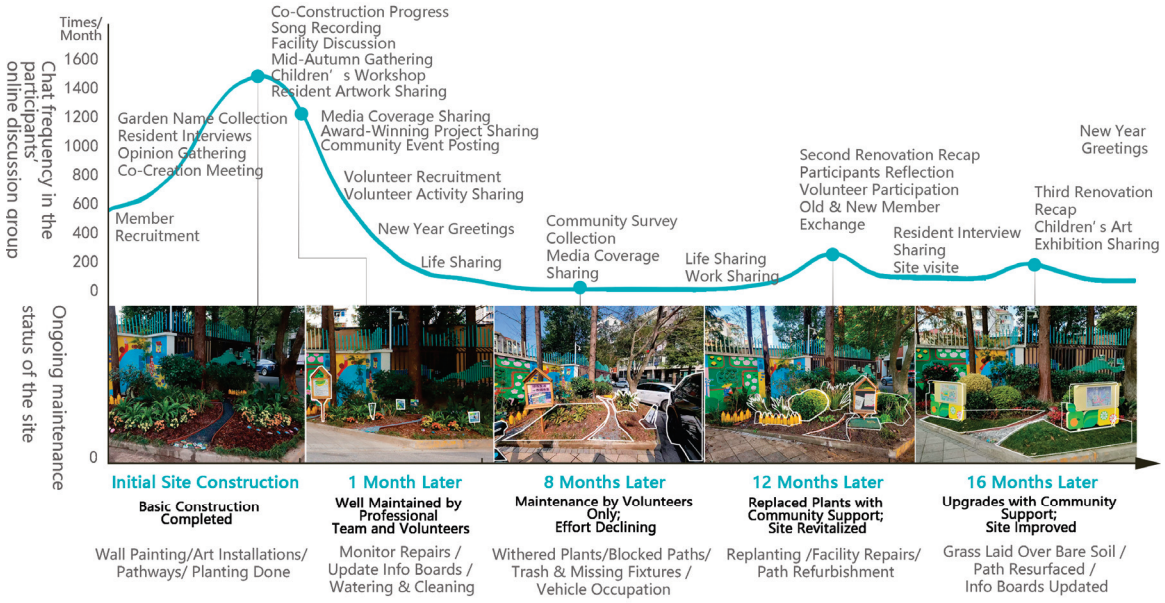

Figure 15. Long-term tracking of post-project maintenance.

The site underwent three rounds of renewal. The first took place during the initial construction phase and was led by an independent team with broad civic participation. During this phase, all participants demonstrated high levels of enthusiasm and engagement, and online activity reached its peak. In the month following the garden's completion, participant engagement declined slightly. However, thanks to continued maintenance by professional teams and volunteers, the site remained in good condition. Subsequently, as the professional team gradually withdrew and handed over maintenance responsibilities to volunteers, the garden began to deteriorate as public interest waned. The second round of renewal occurred 12 months after the garden's completion, initiated by the local neighborhood committee. This intervention revitalized discussion within the online

communication group, generating a new wave of community discourse. The third update was a partial site enhancement, again supported by the neighborhood committee. This progressive, phased approach to renewal allowed the garden to evolve incrementally. With the support of local government and social organizations, the space gradually developed the capacity for autonomous and sustainable maintenance.

These three renewal processes demonstrate that the evolution of community space exhibits phased characteristics. This feature reflects the initial lack of maintenance experience among residents, the government, and volunteers, while also highlighting the natural adaptation period required for plants and the environment to integrate. In practice, the sustainability of the space depends not only on initial enthusiasm but also on the intensity and continuity of subsequent maintenance efforts. Particularly after the gradual withdrawal of professional teams, community-led maintenance can be easily disrupted by factors such as time constraints, energy, and emotional fluctuations, leading to an unstable condition of the space. This process further emphasizes the importance of establishing a comprehensive post-renewal maintenance system and an internal self-governance mechanism within the community to ensure the stability of site operations.

Looking at the entire observation period, it is clear that while uniting various stakeholders is effective in the short term, long-term efforts cause participant enthusiasm and the maintenance capacity of volunteer teams to gradually diminish. At this point, support and intervention from local governments and community committees become particularly crucial. Thus, it is evident that community projects require not only initial infrastructure renovation but also ongoing institutional collaboration in later stages. Ensuring the long-term maintenance of the space can be achieved by integrating multiple pathways, strengthening policy guidance, providing funding support, implementing incentive measures, and assisting in the establishment of maintenance teams.

6. Discuss

6.1. Case Review and Reflection

Under the framework of civic participation in sustainable community renewal, the project demonstrated practical outcomes while also revealing several systemic challenges.

Participatory observation suggested that the project achieved a degree of sustainability. Ecologically, the use of local materials, ecological restoration, and natural cycles helped reduce maintenance labor and operational costs. In terms of participant mobilization, the project successfully engaged families, youth, and elderly residents through differentiated approaches based on psychological and identity characteristics. According to participants, this organization enhanced their sense of pride and ownership. Economically, the integration of external resources from social organizations, enterprises, and universities enabled co-construction with limited input, showing replicability and low-cost potential. Socially, mechanisms such as role rotation and the establishment of a community convention formed a preliminary framework for long-term operation and management.

At the same time, the project faced several limitations. First, in terms of renewal outcomes, the site only reached a relatively stable condition after undergoing three phases of incremental improvement, highlighting the cyclical and phased nature of site maintenance. This is closely related to the organizational stability and sustained participation of the volunteer team and also reflects the lack of a stable governance support mechanism within the community. In addition, the spatial scope of the research site placed certain constraints on the scale and diversity of resident participation. While this spatial limitation was not a major impediment, it nevertheless underscores the importance of developing future action strategies that extend beyond the immediate site. Furthermore, residents' capacity for self-organization and agenda-setting was not fully activated, and the project

remained reliant on facilitation from the research team and local organizations. These issues reflect the current insufficiency of policy support, financial assistance, personnel allocation, and participatory awareness. A more comprehensive framework is needed to support collaborative governance.

Compared with similar community renewal projects in China, such as the Chuangzhi Urban Farm in Shanghai [46], which encourages citizen-led proposals, the Anshansi Community Garden [11], where resident co-creation led to long-term community activities, the Xinqingyayuan Community [26], which shifted from developer control to owner-led management to safeguard rights and improve service quality, and the Shapowei Community in Xiamen [47], which gathered residents' input through participatory planning workshops, this project also adopted a participatory approach. However, its distinct feature lies in its foundation within a sustainable community framework, offering a more comprehensive and multidimensional renewal model. It is also an embedded, full-process practical observation that focuses more on analyzing and interpreting the process rather than solely focusing on outcomes. The research team was involved throughout the project, from the preparation stage of recruiting participants and forming co-creation and co-construction teams, to gaining a detailed understanding of personnel integration. This provides a substantive supplement to understanding organizational logic, motivations for participation, and collaboration mechanisms in community renewal. Overall, while there remains room for improvement in achieving comprehensive long-term self-governance, the project met its expected outcomes in terms of reaching phased objectives and broad-based mobilization. Based on the experience of this project, we summarize the following lessons and insights:

- Experience in Mobilizing Diverse Stakeholders: The core team should include 1–2 middle-aged members (aged 35–50) with organizational and communication skills to handle external coordination and participant recruitment. Active community residents are essential; the involvement of 2–3 such individuals can effectively enhance neighborhood attention and participation. Our core team comprised two such residents, one member from a social organization familiar with community work, two coordinators responsible for recruitment, two volunteers, and two university researchers, forming a comprehensive and efficient collaborative team.
- Experience in Securing Funding and Materials: The project secured funds and materials through various channels, including volunteer donations, support from social organizations, allocations from the community maintenance fund, corporate sponsorships based on mutual benefit, and research funding from universities.
- Experience in Organizing Community Activities: For bottom-up renewal projects, a gradual approach is recommended. Dividing the project into phases allows participants to see tangible progress and gain a sense of achievement. Setting overly ambitious long-term goals in a single phase may lead to fatigue, frustration, and withdrawal due to a lack of visible results. During this period, participant turnover is normal and can even inject new energy, creativity, and momentum into the project.
- Lessons from Planting and Maintenance: When planning ecological improvements or planting vegetation, it is important to select locations with sufficient sunlight and rain, or with accessible water sources to facilitate maintenance. Native species should be prioritized to match soil conditions. Large-leaved plants are preferable to flowering species, as they require less maintenance.
- Site Limitations: Bottom-up community renewal efforts often take place in small-scale spaces, where limited size may restrict the implementation of certain activities. In such cases, the site can function as a communication hub or demonstration space, extending its influence beyond physical boundaries. Alternatively, selecting a larger or more gatherable site at the outset may unlock greater community potential.

The case process and outcomes indicate that, compared with conventional participatory renewal models, civic participation in sustainable community renewal offers stronger integrative potential and practical traction. As urban development enters a new phase characterized by stock-based renewal, ecological transition, and community governance, traditional participatory approaches show limitations in addressing complex local challenges. In this context, this concept of sustainable civic participation gains relevance by emphasizing not only inclusiveness and democratic participation, but also ecological restoration, cultural production, economic operation, and long-term governance mechanisms. It moves beyond the notion that participation is sufficient in itself, redefining the community as an integrated system encompassing ecological, cultural, spiritual, social, and economic dimensions. Civic participation in sustainable renewal thus extends the pathway of participatory models and represents an exploratory process that combines practical experience with theoretical innovation. It offers a multidimensional analytical framework for researchers and a more applicable operational model for practitioners.

6.2. Strategy Promotion and Mechanism Optimization

In response to the effective practices and practical limitations observed in the case, it is necessary to build on existing experience and further develop actionable and transferable strategies and mechanisms. These strategies aim to offer practical guidance on how to achieve sustainable renewal of fragmented small-scale community spaces, particularly under conditions of limited human and material resources.

6.2.1. Ecological Sustainability Strategies for Shaping Physical Space

Ecological sustainability of the physical space serves as the foundation for community renewal efforts. Three key strategies are proposed as follows.

First, help residents build a comprehensive understanding of ecological systems. Before renewal begins, planting workshops, ecological education, and public outreach can guide residents to identify native plants and materials, follow principles of locality, and improve plant survival rates and landscape quality. Promote the 4R principles of ecological design (reduce, reuse, recycle, and regenerate) to encourage ecological cycles. Residents should be encouraged to adopt natural processes to reduce manual maintenance, such as rainwater harvesting, worm towers, soil restoration, and organic waste reuse, in order to create low-maintenance ecosystems.

Second, establish designated collection points for reusable materials. These are set up in-community stations for used items or donations, with clear categories of accepted materials and assigned personnel for sorting to facilitate access and reuse by residents.

Third, provide guidance on the selection of sustainable materials. Emphasizing commonly available items such as plastic bottles, yarn, clothing, and wooden boards encourages residents to repurpose everyday materials creatively. In addition, choosing durable and wind-resistant materials, such as tires and ceramics, can reduce the frequency of replacement and minimize resource consumption and waste generation.

6.2.2. Spiritual–Cultural Sustainability Strategies Through Broad Civic Participation

The sustainable development of cultural and spiritual identity relies on well-structured participation pathways and the strengthening of community identity, which can be advanced through the following strategies aimed at fostering inclusive civic participation.

First, establish effective mobilization strategies. In the early stage, community committees, property management offices, and influential residents can help form initial teams through localized demonstrations and neighbor-to-neighbor outreach, with a focus on engaging middle-aged adults (31–50) and older residents. In the mid-stage, a home–school–community collaboration mechanism can integrate renewal activities into parent–child

education and school practice. On-site interaction points can also be set up to involve temporary residents and broaden project impact. In the later stage, a volunteer-based maintenance mechanism should be established with support from community committees and the project team. This can be reinforced through point systems and public recognition, while schools, social organizations, and local businesses can help build an external support network.

Second, identity recognition across different groups can be activated through customized participation pathways. For example, parent–child families may engage in creative activities such as painting, planting, and crafting. Individual residents can build a sense of belonging through discussion, sharing, and communication. Teenagers may increase initiative through school-based organizations and recognition programs, while older residents can contribute through upcycling, storytelling, and local cultural activities. Group-specific engagement can gradually foster a sense of ownership among diverse participants, providing lasting momentum for emotional cohesion and the sustainable development of community culture.

6.2.3. Multi-Stakeholder Governance and Strategies for Economic Sustainability

Achieving sustainable economic development in communities requires the coordination of diverse resources, optimization of cost structures, and expansion of mixed-use models. The following strategies are proposed to promote the economic sustainability of the community:

First, coordinate resources to optimize costs. Responsibilities should be clearly defined, with the community committee overseeing coordination and ensuring access to space, personnel, and basic support. Resource-wise, mechanisms such as crowdfunding, engagement of skilled residents, material donations, and third-party sponsorship can help alleviate financial and labor pressures. During the maintenance phase, standardized procedures and cost accounting templates can be established, supported by dynamic evaluations and public budgeting, to optimize resource allocation and reduce professional procurement costs. Government subsidies and social capital should be leveraged to promote multi-stakeholder collaboration and ensure efficient and stable operations.

Second, expand diversified spatial uses. In terms of spatial operations, essential functions should be preserved. For instance, agricultural planting areas can be restored and integrated with aromatic and ornamental foliage plants to create edible landscapes that combine ecological, aesthetic, and economic value. The introduction of diverse commercial and social activities should also be encouraged. Drawing on local culture and policy resources, partnerships with businesses, universities, and schools can support co-branding, themed events, and experiential programs, enhancing spatial vibrancy and interaction. To overcome site limitations, the space can serve as a communication platform, while activities may extend beyond the immediate site through external venues or partner support, improving resource efficiency and increasing community returns.

6.2.4. Promoting Social Sustainability Through Maintenance and Safeguard Mechanisms

The mechanisms for strengthening social sustainability through maintenance and safeguards are as follows.

First, establish top-down institutional support. Dedicated community roles, such as planners, renewal coordinators, and management teams, should be created to oversee daily decision-making and project advancement. These positions should provide context-specific implementation proposals to improve policy support and administrative efficiency. Special funding should be allocated with a dual focus on incentives and subsidies: rewarding active contributions from residents and organizations while supporting collaborative ini-

tiatives such as university competitions and community projects. A multi-stakeholder co-governance platform should be built to integrate resources from businesses, students, volunteers, and civil organizations, enabling regular consultation and flexible coordination to enhance community self-governance.

Second, develop bottom-up self-organization models. By regularly providing public spaces and platforms, residents are empowered to independently initiate activities, reinforcing their agency, decision-making capacity, and sense of ownership in the renewal process. Incentive mechanisms should be designed, combined with clearly defined cooperative participation, to enhance residents' sense of agency and their sense of belonging to the community. At the same time, promoting resource sharing and role-based empowerment can stimulate everyday interactions among community members, further enhancing their active participation, cohesion, and collective identity.

Third, implement flexible participation and maintenance mechanisms. Schools, local businesses, residents, and volunteers should be encouraged to form spontaneous teams and engage in routine maintenance through interest-based responsibilities and rotational collaboration. On the basis of broad consultation, a community convention can be developed to promote voluntary care, building a co-managed and open system that enables self-regulation and autonomous operation.

7. Conclusions

This study is a case-based investigation of participatory community renewal guided by the concept of sustainability. The case was primarily led by the research team, which mobilized multiple forces and resources to construct a recyclable renewal system while minimizing government financial input. On this basis, the study adopted the framework of "civic participation in sustainable community renewal" and integrated the concept of sustainable development into participatory practices, aiming to explore long-term renewal pathways for community spaces across four dimensions: ecological, spiritual–cultural, economic, and social.

The study mainly employed participatory observation methods, analyzing from three aspects: participant composition, behavioral and emotional changes, and long-term observation. The results on participant composition show that minors and family-based participants accounted for the highest proportion. Different types of participants were drawn to different stages of the project, and people of different identities played various roles within the team. In terms of behavior and emotions, the renewal process had a relatively small emotional impact on those who actively participated from the beginning, but a greater emotional influence on those who were initially indifferent but gradually became involved during the process. Residents who participated in co-construction had higher recognition and evaluation of the site than those who did not, and they showed a stronger sense of responsibility for site maintenance. Activities with artistic value and universal accessibility were generally welcomed by all age groups and showed higher levels of participation. Follow-up observation revealed that the status of site maintenance and the frequency of online communication fluctuated in parallel at several time points and that the involvement of community committees and other institutions played a significant role in reactivating the site. In addition, relying solely on short-term enthusiasm from participants was insufficient to sustain long-term development, and further institutional support was required. Therefore, effective renewal depends not only on early stage mobilization, but also on the establishment of post-renewal support mechanisms and the cultivation of self-organizing systems.

At the level of strategies and mechanisms, the study summarizes four types of pathways: (1) in terms of ecological sustainability, it is recommended to create low-maintenance

and highly resilient natural systems through ecological knowledge dissemination, the establishment of material sorting points, and the optimization of material usage. (2) In the spiritual–cultural dimension, by identifying psychological characteristics of different groups and designing appropriate activities, participants' sense of identity and community belonging can be enhanced. (3) In the economic dimension, the strategy combines the introduction of diverse economic models with cost optimization to achieve a low-cost and recyclable operation model. (4) In the area of social governance, the study emphasizes the construction of a compound mechanism that integrates top-down policy support, bottom-up organizational mobilization, and voluntary maintenance, in order to promote the institutionalization of co-construction and co-governance in the community.

In general, current community renewal has gradually entered a governance stage that emphasizes both institutional coordination and relational negotiation. The pathway of civic participation in sustainable community renewal, through the multidimensional integration of ecological embedding, mechanism construction, and relational networks, provides replicable strategies and mechanisms to address the problems of insufficient maintenance and declining participation following renewal efforts. It offers a reference and practical model for community governance and spatial transformation in the context of urban stock renewal.

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References

1. Berger, A.S. *The City: Urban Communities and Their Problems*; Brown: Providence, RI, USA, 1978.
2. Dai, P.; Fu, H.; Yang, X.; Han, S.; Fu, G.; Wang, Y. Exploring the urban renewal strategy based on transit-oriented development concept--A case study of Japan and Hong Kong. *Front. Mater.* **2023**, *10*, 1098027. [CrossRef]
3. Cui, L.; Shi, J. Urbanization and its environmental effects in Shanghai, China. *Urban Clim.* **2012**, *2*, 1–15. [CrossRef]
4. Shanghai Municipal People's Government. Shanghai City Master Plan (2017–2035). Available online: https://www.shanghai.gov.cn/cmsres/35/35e861ed66094c98b2313045cc26bb29/9c6dfadaa48bc19a50297fb66f6610e5.pdf (accessed on 19 June 2025).
5. Ji, H. Inter-community participatory social network analysis: Re-envisioning humanitarian accountability with climate-related displaced communities in Bangladesh. *Disaster Prev. Manag. Int. J.* **2025**, *34*, 133–146. [CrossRef]
6. Li, K.; Huang, R.; Liu, G.; Shrestha, A.; Fu, X. Social Capital in Neighbourhood Renewal: A Holistic and State of the Art Literature Review. *Land* **2022**, *11*, 1202. [CrossRef]
7. Li, L.; Zhu, J.; Duan, M.; Li, P.; Guo, X. Overcoming the Collaboration Barriers among Stakeholders in Urban Renewal Based on a Two-Mode Social Network Analysis. *Land* **2022**, *11*, 1865. [CrossRef]

8. Sun, S.; Chen, R.; Qin, S.; Liu, L. Evaluating the Public Participation Processes in Community Regeneration Using the EPST Model: A Case Study in Nanjing, China. *Land* **2022**, *11*, 1405. [CrossRef]
9. Kim, G.; Newman, G.; Jiang, B. Urban regeneration: Community engagement process for vacant land in declining cities. *Cities* **2020**, *102*, 102730. [CrossRef]
10. Clark, J.; Wise, N. *Urban Renewal, Community and Participation: Theory, Policy and Practice*; Springer: Berlin/Heidelberg, Germany, 2018. [CrossRef]
11. Zhong, X.; Leung, H.H. Exploring participatory microregeneration as sustainable renewal of built heritage community: Two case studies in Shanghai. *Sustainability* **2019**, *11*, 1617. [CrossRef]
12. Roberts, P.; Sykes, H. *Urban Regeneration: A Handbook*; Sage: London, UK, 1999; p. 10.
13. Couch, C. *Urban Renewal: Theory and Practice*; Springer: Berlin/Heidelberg, Germany, 1990; p. 06.
14. Metta, M.; Ciliberti, S.; Obi, C.; Bartolini, F.; Klerkx, L.; Brunori, G. An integrated socio-cyber-physical system framework to assess responsible digitalisation in agriculture: A first application with Living Labs in Europe. *Agric. Syst.* **2022**, *203*, 103533. [CrossRef]
15. Næss, P.; Saglie, I.-L.; Richardson, T. Urban sustainability: Is densification sufficient? *Eur. Plan. Stud.* **2020**, *28*, 146–165. [CrossRef]
16. Jacobs, J. *Death and Life of Great American Cities*; The Bodley Head: London, UK, 2020.
17. Lane, M.B. Public participation in planning: An intellectual history. *Aust. Geogr.* **2005**, *36*, 283–299. [CrossRef]
18. Arnstein, S.R. A Ladder Of Citizen Participation. *J. Am. Inst. Plan.* **1969**, *35*, 216–224. [CrossRef]
19. Sun, C.; Liu, J.; Chen, Y. Impact of empowerment on public participation awareness in community renewal projects: Mediating role of trust and community identity. *J. Asian Archit. Build. Eng.* **2025**, *24*, 1931–1944. [CrossRef]
20. Habermas, J. *The Theory of Communicative Action: Volume 2: Lifeword and System: A Critique of Functionalist Reason*; Beacon Press: Boston, MA, USA, 1985; Volume 2, p. 140.
21. Marcucci, D.J.; Brinkley, J.D.; Jordan, L.M. A Case for Coastal Theory with Lessons from Planning Theory. *Coast. Manag.* **2012**, *40*, 401–420. [CrossRef]
22. Sutriadi, R. A Communicative City as a Preliminary Step towards a Technopolis Agenda. *Procedia-Soc. Behav. Sci.* **2016**, *227*, 623–629. [CrossRef]
23. World Commission on Environment and Development. Our Common Future (Brundtland Report). Available online: https://www.are.admin.ch/are/en/home/media/publications/sustainable-development/brundtland-report.html (accessed on 15 July 2025).
24. Syamsiyah, N.; Sadeli, A.H.; Saidah, Z.; Noor, T.I.; Widiyanesti, S. Community Participation in the Development of Sustainable, Environmentally Conscious Villages in the Cirasea Sub-Watershed, Indonesia. *Sustainability* **2025**, *17*, 4871. [CrossRef]
25. Huang, W.; Hu, L.; Xing, Y. Sustainable Renewal Strategies for Older Communities from the Perspective of Living Experience. *Sustainability* **2022**, *14*, 2813. [CrossRef]
26. Zhang, Z.; Yu, J.; Tian, J. Community Participation, Social Capital Cultivation and Sustainable Community Renewal: A Case Study from Xi'an's Southern Suburbs, China. *J. Knowl. Econ.* **2024**, *15*, 11007–11040. [CrossRef]
27. Yang, J.; Yang, L.; Ma, H. Community Participation Strategy for Sustainable Urban Regeneration in Xiamen, China. *Land* **2022**, *11*, 600. [CrossRef]
28. Meadowcroft, J. Participation and Sustainable Development: Modes of Citizen, Community and Organisational Involvement. *Gov. Sustain. Dev. Chall. Adapt. Form Funct.* **2004**, 162–190. [CrossRef]
29. Healey, P. *Collaborative Planning: Shaping Places in Fragmented Societies*; Bloomsbury Publishing: London, UK, 2020; p. 5.
30. Pretty, J. Social capital and the Collective management of resources. *Science* **2003**, *302*, 1912–1914. [CrossRef]
31. Yamazaki, K. Case Studies on Japanese MNEs: Global Strategy. In *Japanese Global Strategy: Overseas Operations and Global Marketing*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 55–122.
32. Studio-L. Arima Fuji Park Management. Available online: https://www.studio-l.org/en/service/01_arimafuji.html (accessed on 14 July 2025).
33. Mirabal, N.R. Geographies of displacement: Latina/os, oral history, and the politics of gentrification in San Francisco's Mission District. *Public Hist.* **2009**, *31*, 7–31. [CrossRef]
34. Fernández, J.S.; Nichols, L.A. Mosaicos de la Comunidad (Mosaics of the Community): Community-Engaged Participatory Muraling with Madres Emprendedoras. *Soc. Sci.* **2025**, *14*, 25. [CrossRef]
35. Lacy, S. *Mapping the Terrain: New Genre Public Art*; Bay Press: Seattle, WA, USA, 1995; p. 27.
36. Colantonio, A.; Dixon, T.; Ganser, R.; Carpenter, J.; Ngombe, A. Measuring Socially Sustainable Urban Regeneration in Europe. Available online: https://www.academia.edu/8329602/Measuring_Socially_Sustainable_Urban_Regeneration_in_Europe (accessed on 14 July 2025).
37. Chance, T. Towards sustainable residential communities; the Beddington Zero Energy Development (BedZED) and beyond. *Environ. Urban.* **2009**, *21*, 527–544. [CrossRef]
38. Zhang, Z.; Pan, J.; Qian, Y. Collaborative Governance for Participatory Regeneration Practices in Old Residential Communities within the Chinese Context: Cases from Beijing. *Land* **2023**, *12*, 1427. [CrossRef]

39. Chen, W.; Cheshmehzangi, A.; Mangi, E.; Heath, T.; Ye, C.; Wang, L. An Analysis of Residents' Social Profiles Influencing Their Participation in Community Micro-Regeneration Projects in China: A Case Study of Yongtai Community, Guangzhou. *Land* **2022**, *11*, 790. [CrossRef]
40. World Health Organization. United Nations Conference on Environment and Development. Available online: https://iris.who.int/bitstream/handle/10665/171232/EB91_Inf.Doc-5_eng.pdf (accessed on 19 June 2025).
41. Hens, L.; Nath, B. The johannesburg conference. *Environ. Dev. Sustain.* **2003**, *5*, 7–39. [CrossRef]
42. Malinowski, B. *Argonauts of the Western Pacific: An Account of Native Enterprise and Adventure in the Archipelagoes of Melanesian New Guinea [1922/1994]*; Routledge: Oxfordshire, UK, 2013.
43. Lindeman, E.C.; Croly, H. *Social Discovery*; Republic Publishing Company: New York, USA, 1924.
44. Roque, A.; Wutich, A.; Brewis, A.; Beresford, M.; Landes, L.; Morales-Pate, O.; Lucero, R.; Jepson, W.; Tsai, Y.; Hanemann, M.; et al. Community-based Participant-observation (CBPO): A Participatory Method for Ethnographic Research. *Field Methods* **2023**, *36*, 80–90. [CrossRef]
45. Tajfel, H.; Turner, J.C.; Austin, W.G.; Worchel, S. An integrative theory of intergroup conflict. *Organ. Identity A Read.* **1979**, *56*, 94–109.
46. Kou, H.; Zhang, S.; Liu, Y. Community-Engaged Research for the Promotion of Healthy Urban Environments: A Case Study of Community Garden Initiative in Shanghai, China. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4145. [CrossRef]
47. Hui, E.C.-m.; Chen, T.; Lang, W.; Ou, Y. Urban community regeneration and community vitality revitalization through participatory planning in China. *Cities* **2021**, *110*, 103072. [CrossRef]

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Dynamic Assessment of Street Environmental Quality Using Time-Series Street View Imagery Within Daily Intervals

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Abstract: Rapid urbanization has intensified global settlement density, significantly increasing the importance of urban street environmental quality, which profoundly affects residents' physical and psychological well-being. Traditional methods for evaluating urban environmental quality have largely overlooked dynamic perceptual changes occurring throughout the day, resulting in incomplete assessments. To bridge this methodological gap, this study presents an innovative approach combining advanced deep learning techniques with time-series street view imagery (SVI) analysis to systematically quantify spatio-temporal variations in the perceived environmental quality of pedestrian-oriented streets. It further addresses two central questions: how perceived environmental quality varies spatially across sections of a pedestrian-oriented street and how these perceptions fluctuate temporally throughout the day. Utilizing Golden Street, a representative living street in Shanghai's Changning District, as the empirical setting, street view images were manually collected at 96 sampling points across multiple time intervals within a single day. The collected images underwent semantic segmentation using the DeepLabv3+ model, and emotional scores were quantified through the validated MIT Place Pulse 2.0 dataset across six subjective indicators: "Safe," "Lively," "Wealthy," "Beautiful," "Depressing," and "Boring." Spatial and temporal patterns of these indicators were subsequently analyzed to elucidate their relationships with environmental attributes. This study demonstrates the effectiveness of integrating deep learning models with time-series SVI for assessing urban environmental perceptions, providing robust empirical insights for urban planners and policymakers. The results emphasize the necessity of context-sensitive, temporally adaptive urban design strategies to enhance urban livability and psychological well-being, ultimately contributing to more vibrant, secure, and sustainable pedestrian-oriented urban environments.

Keywords: street environmental quality; time-series street view imagery; pedestrian-oriented streets; perceptual analysis; urban design

1. Introduction

In recent decades, rapid urbanization has significantly reshaped global settlement patterns, leading more than half of the world's population—and approximately three-quarters of economic activities—to concentrate in urban areas [1,2]. The physical quality of urban environments profoundly influences residents' daily activities, social interactions, and overall sense of well-being [3]. Urban streets, as multifunctional public spaces, integrate social, economic, and cultural dimensions. They serve as critical arenas for communal interactions and public life, reflecting broader urban social dynamics [4]. Streets often represent the

most fundamental spatial units for observing public behaviors, social interactions, and communal values [5]. Recent research further underscores the significant impacts street quality exerts on human health, psychological well-being, and overall urban livability [6]. Consequently, accurately assessing and quantifying street environments is increasingly important for understanding residents' perceptions and informing effective urban renewal and development initiatives.

Technological advancements, particularly the integration of deep learning techniques with street view imagery (SVI), have enabled rapid, large-scale, and automated assessments of human perceptions regarding urban built environments, significantly surpassing traditional methods based on manual or survey-driven evaluations [7]. While existing research utilizing SVI effectively highlights spatial disparities in environmental attributes, it predominantly neglects temporal variations, thus inadequately addressing the dynamic nature of human environmental perceptions over time. Specifically, the update frequency of SVI has long been problematic. In certain regions, image acquisition rates are low and often outdated, failing to provide sufficient data for current-status monitoring, update analysis, or activation time analysis (e.g., change detection). Moreover, the service does not support historical image queries by design, and inconsistencies may arise from different parts of the same city being imaged at varying times. The timing of image collection also poses challenges: First, image capture may mismatch required research cycles or other datasets used in studies. Second, the timing of annual data collection itself could introduce bias [8,9].

Furthermore, despite their centrality to urban life and interactions, living streets–pedestrian-oriented streets emphasizing community activities, leisure, and social engagements—remain underrepresented in empirical research employing SVI. Addressing these identified research gaps, this study proposes an innovative approach integrating advanced deep learning models with time-series SVI to systematically evaluate street environmental quality across spatial and temporal dimensions. By applying this approach, this study aims to identify key environmental attributes requiring enhancement, thereby facilitating targeted improvements to promptly enhance residents' satisfaction and urban livability. This research specifically investigates two key questions:

1. How does the perception of street environmental quality at different locations on the same street change dynamically over time within a day, and what kind of spatial variation patterns are presented by such dynamic changes?

2. How does the perception of street environmental quality fluctuate dynamically over time of the day at the same location on the street, and what identifiable patterns emerge from these temporal dynamics?

To systematically explore these questions, this research employs a methodological framework anchored in six rigorously selected subjective perception indicators: "Safe," "Lively," "Boring," "Wealthy," "Depressing," and "Beautiful." These indicators were chosen based on their established reliability, broad applicability, and effectiveness in capturing nuanced emotional and perceptual responses in urban environmental studies [10–12]. Utilizing deep learning models trained on validated perceptual datasets, this study generated detailed, quantifiable indicator scores that enable precise comparisons of environmental quality across different spatial locations and time periods.

Golden Street, located in the Gubei area of Shanghai's Changning District, serves as the empirical context for this study. Spanning approximately 700 m with widths ranging from 40 to 80 m, Golden Street integrates vibrant commercial, leisure, and community functions, resulting in consistently high pedestrian activity and social interaction [13]. As one of Shanghai's earliest international residential districts, the perceptual experiences of residents regarding environmental quality on Golden Street hold considerable importance

for urban planning and quality-of-life enhancement. Consequently, this study pursues three specific objectives: firstly, to analyze the spatial differences in street environment perception at different times in a day and reveal the dynamic spatial variations using a deep learning method; secondly, to explore how the environmental perception of fixed street locations fluctuates dynamically over different periods of time and analyze the dynamic change patterns of perception within a day; thirdly, to reveal the dynamic influence mechanism of environmental characteristics in the time dimension by deeply exploring the correlation between the dynamic time-series change in street environment perception and the physical characteristics of streets.

Collectively, achieving these objectives will provide nuanced insights and robust empirical evidence to inform targeted, context-specific urban renewal strategies and policy interventions.

2. Related Work

2.1. Analyzing Street View Imagery through Deep Learning

Efficiently and economically assessing the environmental quality of urban streets has historically posed methodological challenges. Recent advances in semantic segmentation techniques, particularly within deep learning frameworks, have provided new opportunities to address these issues. Semantic segmentation enables the detailed extraction and analysis of environmental components within street view imagery (SVI), significantly surpassing traditional manual methods in terms of scale, efficiency, and accuracy.

Google Street View (GSV), launched in 2007, has become a widely utilized global mapping tool, currently covering approximately half the world's population and frequently employed in urban studies [14,15]. Images from GSV are typically collected by vehicles equipped with GPS and sophisticated sensor arrays, capturing panoramic photos annotated with precise spatial coordinates. Previous research has confirmed that street view images provide a more accurate representation of urban environments as experienced by pedestrians, in contrast to aerial imagery and other remote sensing sources, due to their alignment with actual human visual perspectives [16,17].

Deep learning techniques, especially semantic segmentation, effectively manage the inherent complexity of urban street scenes by identifying detailed patterns from large-scale, multidimensional datasets [18]. Earlier image datasets often encountered difficulties in accurately capturing urban streetscape variability caused by lighting changes, visual obstructions, and the diverse nature of urban elements. However, the introduction of the Place Pulse 2.0 dataset developed by MIT represents an advancement. This dataset encompasses over 110,000 street view images from cities worldwide and includes more than 1.1 million pairwise comparisons across six subjective perceptual dimensions: "Safe," "Lively," "Boring," "Wealthy," "Depressing," and "Beautiful" [19]. These dimensions encompass the primary emotional responses and social perceptions people may develop in urban spaces. Key elements include "Safe," which directly influences behavioral decisions and comfort levels; "Wealthy," reflecting regional economic development and resource distribution; esthetic experiences like "Beautiful" and "Depressing," which impact mental health and residential satisfaction; and "Lively," indicating social engagement and living atmosphere within the area [20]. These corresponding contents are consistent with the improvement of living environment quality and the reconstruction of commercial vitality in the "Changning District Urban Renewal 2025-2027 Action Plan."

The Place Pulse 2.0 dataset has facilitated advances in urban studies. For example, Wei et al. (2022) employed this dataset to map urban landscape perceptions in central Shanghai, revealing a clear preference for administrative and service-oriented areas and demonstrating how green spaces significantly reduce perceptions of depression [21]. Simi-

larly, Zhang et al. (2021) explored correlations between perceived safety and actual crime rates in Houston, highlighting the practical utility of perceptual data in urban safety research [22]. Therefore, Place Pulse 2.0 serves as a crucial resource for urban designers and policymakers aiming to improve urban environmental quality through targeted interventions.

2.2. Human Perception of Urban Street Environments

Human perception of urban environments is inherently subjective, influenced by various individual and contextual factors [21]. Nevertheless, integrating SVI with deep learning models provides a novel and reliable approach for quantifying these subjective perceptions at a large scale [11,19]. Since vision constitutes the primary sensory modality through which individuals perceive their surroundings, visual assessment is particularly valuable for evaluating urban landscapes [23]. Although SVI does not perfectly replicate dynamic human visual experiences, these images serve as robust static representations suitable for large-scale perceptual studies.

Quantifying subjective perceptions directly is challenging; however, relative judgment methods—such as those employed in the Place Pulse 2.0 dataset—simplify complex perceptual evaluations effectively. Previous studies have validated pairwise comparison methods across diverse contexts, including educational preferences and taste assessments, affirming their reliability in environmental perception research [24,25]. Moreover, perceptual responses frequently correlate with tangible environmental characteristics. For instance, Smardon (1988) established that people typically prefer natural landscapes featuring rich vegetation and water elements [26]. Expanding on this, Liu et al. (2024) demonstrated significant inverse correlations between the presence of vegetation (such as trees, shrubs, and grass) and urban crime rates, further underscoring the profound influence of physical environmental attributes on subjective perceptions [27]. Therefore, deep learning analyses of SVI represent a compelling method for systematically understanding human perceptions of urban street environments.

2.3. Challenges in Analyzing SVI Using Time-Series Approaches

Despite the prevalence of SVI-based analyses, most existing studies neglect temporal dynamics, focusing predominantly on spatial variability at single points in time [8,28]. Such static perspectives inadequately capture the dynamic complexity inherent in evolving urban spaces. Additionally, widely used deep learning models, such as PlaceCNN, currently do not explicitly incorporate temporal variables, creating a methodological gap in understanding perceptual variations over time.

Street environments inherently exhibit temporal variability, influenced by fluctuating factors such as natural lighting, weather conditions, pedestrian density, and commercial activities. These temporal variations significantly affect perceived environmental quality, underscoring the importance of continuously monitoring and evaluating such changes. Time-series street view imagery thus provides a promising approach for capturing these dynamic variations in environmental quality. However, despite the increasing availability of such data, systematic urban monitoring using time-series imagery remains relatively sparse in the literature [29,30], particularly concerning pedestrian-oriented or living streets.

Critically, few studies have utilized the Place Pulse 2.0 dataset to assess temporal dynamics in human perceptions of living street quality specifically. This notable research gap highlights the need for empirical investigations that systematically explore temporal perceptual changes in pedestrian-centric urban contexts. Addressing this gap, the current study explicitly incorporates a temporal dimension in analyzing perceptual variations, substantially contributing to the methodological advancement of urban environmental assessments.

3. Methodology

3.1. Research Framework

The methodological framework adopted in this study comprises three interconnected stages, as illustrated in Figure 1 : (1) data collection, (2) data processing and scoring, and (3) result calculation and comparative analysis. In the first stage, sampling points were systematically determined to capture street view imagery (SVI) at multiple locations along Golden Street and at multiple time intervals within a single day.

The second stage involved advanced data processing using deep learning techniques. Specifically, the collected SVI was initially segmented semantically using the DeepLabv3+ model, trained on the Cityscapes dataset, to accurately identify critical environmental features. Subsequently, these segmented images were analyzed using the MIT Place Pulse 2.0 dataset, which provided quantified emotional scores across six subjective indicators: "Safe," "Lively," "Wealthy," "Beautiful," "Depressing," and "Boring." Each image received detailed scores for these perceptual indicators, enabling comprehensive comparative analyses across different locations and time intervals.

In the third stage, the emotional scores were systematically analyzed and visualized. Heat maps were generated to illustrate spatial and temporal variations in environmental perceptions clearly. Correlation analyses were then conducted to explore relationships among the six perceptual indicators and between these indicators and their spatial–temporal distribution. The outcomes provided insights into environmental quality trends, facilitating informed and targeted strategies for street improvement.

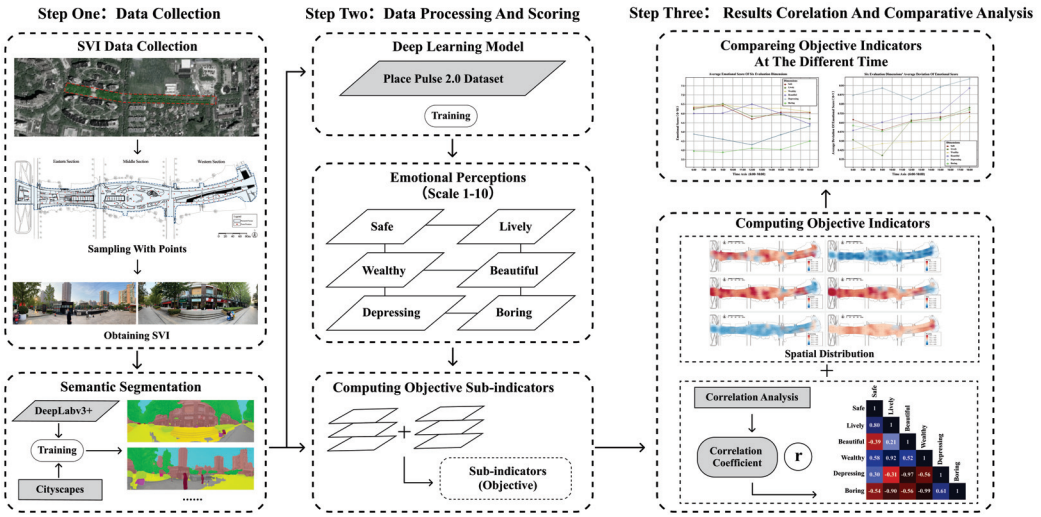

Figure 1. Overall framework of the study.

3.2. Study Area

Golden Street, located in Shanghai's Changning District, was selected as the empirical study area due to its distinctive characteristics as a pedestrian-oriented living street. Designed by SWA Group, Golden Street covers approximately 4.6 hectares, connecting six adjacent residential communities and facilitating social interactions and pedestrian vibrancy. The street integrates diverse commercial, recreational, and leisure spaces, maintaining consistently high pedestrian activity levels and varied usage patterns (Figure 2). The six residential areas proximate to Golden Street had a combined population of 12,200 and exhibited an evenly distributed age composition; this further enhances the representativeness of this study regarding urban environmental perceptions [13].

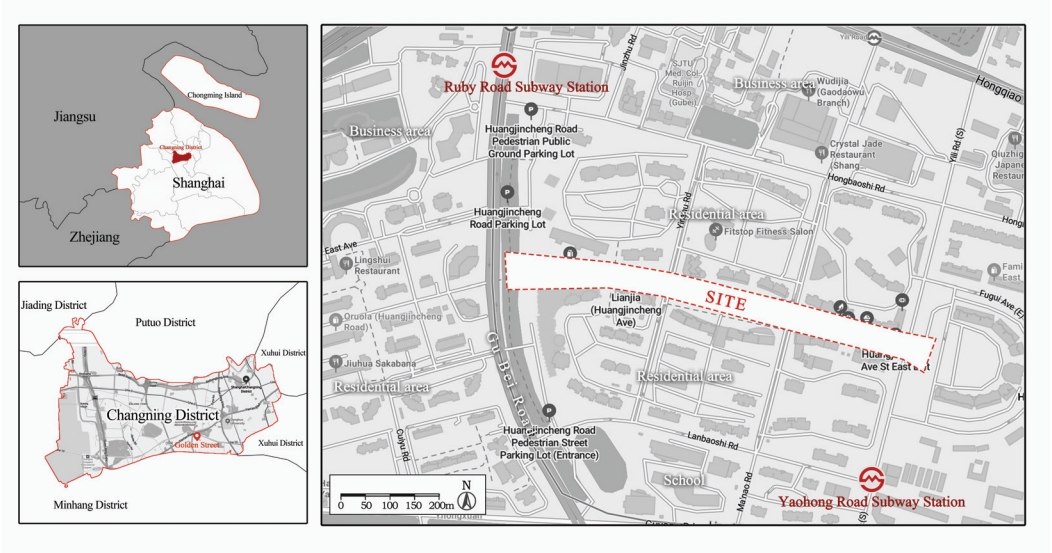

Figure 2. Location map showing Golden Street.

3.3. MIT Place Pulse 2.0 Dataset and Perceptual Indicators

The MIT Place Pulse 2.0 dataset serves as a robust foundation for quantifying environmental perceptions using crowdsourced geographic information systems (GISs) and pairwise comparisons, overcoming limitations of traditional survey-based methods, such as insufficient sample sizes and limited spatial coverage [31]. The dataset includes over 110,000 street view images from 56 global cities, annotated through more than 1.1 million pairwise comparative assessments across six validated subjective perception dimensions: "Safe," "Lively," "Wealthy," "Beautiful," "Depressing," and "Boring." These dimensions capture a wide range of emotional and perceptual responses relevant to urban quality of life, influencing individual behaviors, economic perceptions, psychological comfort, and overall satisfaction with urban environments.

Participants performed forced-choice pairwise comparisons (e.g., determining "Which image appears safer?"). The results were modeled using the Bradley–Terry model, based on Thurstone's Law of Comparative Judgment (1927) [32], converting subjective preferences into quantifiable emotional scores.

$$P(i > j) = \frac{e^{\theta_i}}{e^{\theta_i} + e^{\theta_j}} \quad (1)$$

The Bradley–Terry model is robust and widely applicable, effectively generating continuous emotional scores from pairwise comparison data, facilitating comparative analyses across different images and perceptual dimensions [33,34]. This rigorous methodological approach ensures precise quantification and reliable interpretation of human perceptions of street environmental quality.

3.4. Data Collection

Since GSV imagery is unavailable for pedestrian-only streets, we manually collected street view imagery. According to Alexander, objects such as faces can be recognized at about 70 feet [35], and given the maximum effective shooting range (approximately 20 m) of our equipment, sampling points were established at 20-m intervals along Golden Street. This approach ensured comprehensive spatial coverage while maintaining data validity, initially resulting in 105 sampling points. Following quality control procedures that removed invalid images, 96 sampling points remained valid for analysis (Figure 3).

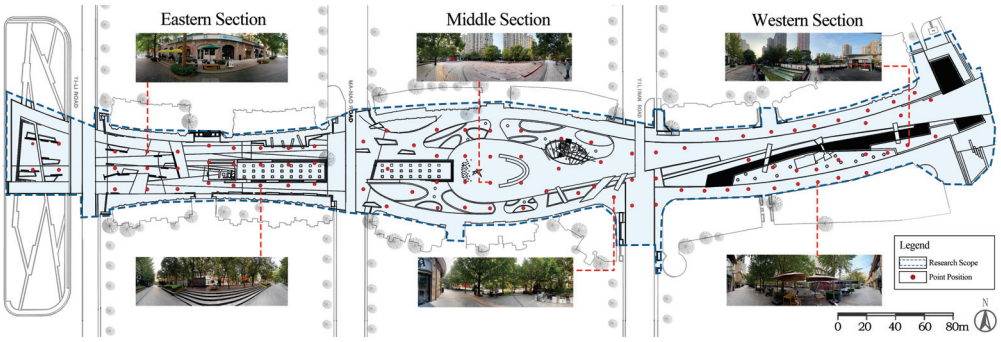

Figure 3. Selection of study area.

To address the limitations of conventional directional methods, which often fail to replicate pedestrian perspectives adequately, we adopted an optimized panoramic photography approach. Specifically, two opposing 180° panoramic images were captured at each sampling location, oriented parallel to the street's primary axis (west-to-east and east-to-west). This technique minimized sampling errors, perspective distortions, and ensured comprehensive visual coverage. For instance, Figure 4 illustrates two panoramic SVIs captured at points A and B (labeled as A1, A2, B1, and B2).

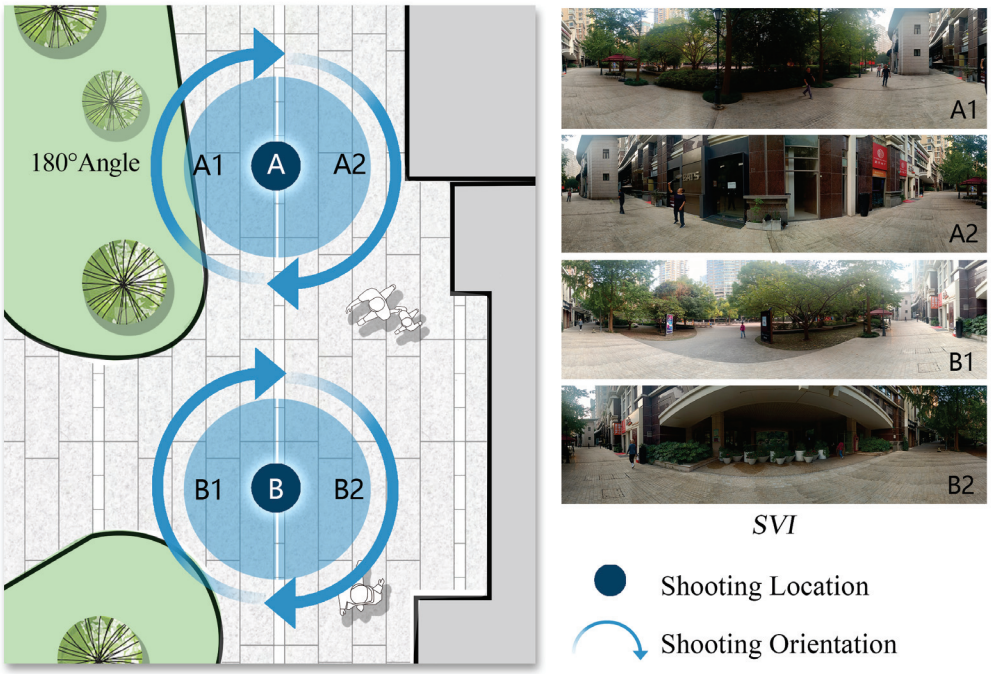

Figure 4. Collection of SVI.

All images were captured under controlled conditions: at an eye-level height of approximately 1.7 m, with a horizontal field-of-view of 90° and vertical orientation at 0°, closely approximating typical human visual perspectives [36]. In the selection of the shooting date, it is considered that holidays and other special festivals may lead to significant changes in factors such as human flow, which makes the experimental data not universal. Data collection occurred during clear weather conditions on weekdays in July 2024, from 6:00 a.m. to 6:00 p.m., at three-hour intervals, with a consistent average temperature of approximately 33 °C. These controlled measures ensured the representativeness and generalizability of the dataset, resulting in a total of 960 images. Ethical considerations were strictly adhered to by anonymizing sensitive personal information, such as faces and license plates, in all collected imagery.

The three-hour interval was determined through our pilot study. During testing, we observed that collecting a full SVI dataset requires approximately 1.5 h and necessitates the real-time verification of data availability, with additional sampling required when necessary. Therefore, in developing the formal research methodology, we established a 3 h data collection cycle to ensure systematic data availability. For the collected SVI data, we carried out manual checks to prevent improper operations during data collection from affecting the final data analysis results. Photos that did not meet the shooting standards were deleted, and supplementary photos were taken within the same time period to ensure the reliability of collected data as much as possible.

3.5. Deep Learning Model for Assessing Street Environmental Quality

The subsequent analysis required building a predictive deep learning model to estimate subjective emotional scores based on collected street view imagery. The primary objective of this model was to predict scores for six perceptual indicators: "Safe," "Lively," "Beautiful," "Wealthy," "Depressing," and "Boring."

Among existing models suitable for extracting semantic information from street images, the DeepLabv3+ model—based on Atrous Convolution and Atrous Spatial Pyramid Pooling (ASPP)—has demonstrated superior performance, effectively capturing multi-scale street view features [37]. We trained this model using the Cityscapes dataset, a widely recognized dataset optimized for urban scene analysis [38]. This combination has been successfully applied in similar street environmental quality studies [39,40].

DeepLabv3+ set the new state-of-the-art standard on the PASCAL VOC-2012 semantic image segmentation task, reaching 79.7 percent mIOU on the test set and improved on the results on three other datasets: PASCAL-Context, PASCAL-Person-Part, and Cityscapes. All of its code has been made publicly available online [41]. The DeepLabv3+ training results for accuracy, F1, precision, and recall values were 96.47%, 85.29%, 92.07%, and 81.84%, respectively. On the crack segmentation task, FCN and DeepLabv3+ achieved training F1 scores of 79.95% and 85.29%. Clearly, DeepLabv3+ outperforms FCN [42]. DeepLabv3+ integrates Atrous Convolution within an encoder–decoder structure. Atrous Convolution enlarges the receptive field by introducing spacing ("Atrous") within the convolution kernel. Its mathematical formulation is defined as follows [41]:

$$\text{Output Size} = \frac{\text{Input Size} + 2p - k - (k-1)(r-1)}{\text{Stride}} + 1 \quad (2)$$

where p is the padding, k denotes the convolution kernel size and r represents the dilation rate. Increasing r enlarges the effective receptive field without additional parameters or computation.

Cityscapes consists of stereo video sequences captured in streets across 50 different cities, comprising 5000 high-quality pixel-level annotations and 20,000 additional images with coarse annotations [38]. With this framework, semantic segmentation was performed on both Place Pulse 2.0 and our collected SVI. Emotional scores from Place Pulse 2.0 were subsequently integrated with the semantically segmented data to train our deep learning model, which then provided emotional scores for all 960 SVIs (Figure 5).

Liu et al. (2022) proposed a new semi-supervised semantic segmentation method based on consistency. With Deeplabv3+ as the architecture, different samples were randomly extracted from the dataset to serve as the training set, and the test model was used to show the generalization ability of different data [43]. We conducted internal quality control on the semantically segmented SVI via random sampling. A total of 96 randomly selected SVIs (10%) were manually verified, with their features extracted as "human-generated images" for comparison against the "segmented images". The analysis demonstrated a calculation accuracy rate exceeding 92%, confirming the reliability of the data (Figure 6).

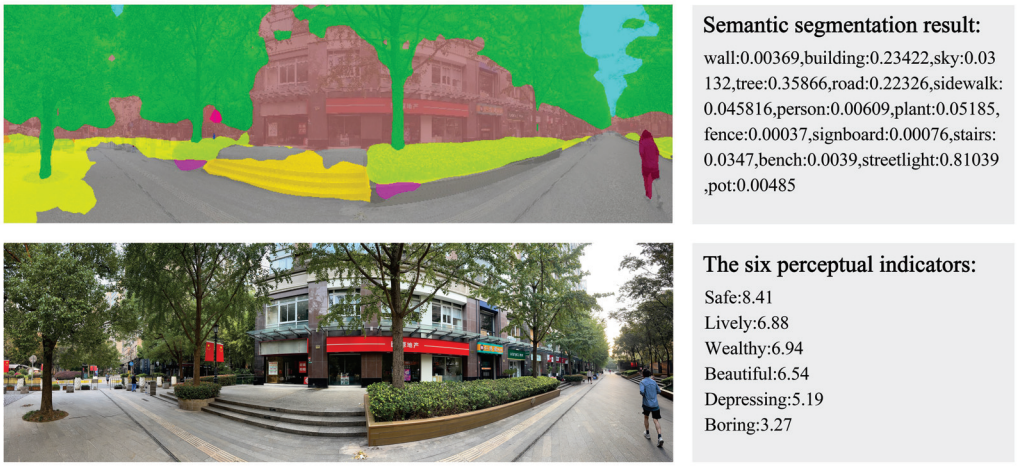

Figure 5. Example of SVI feature extraction.

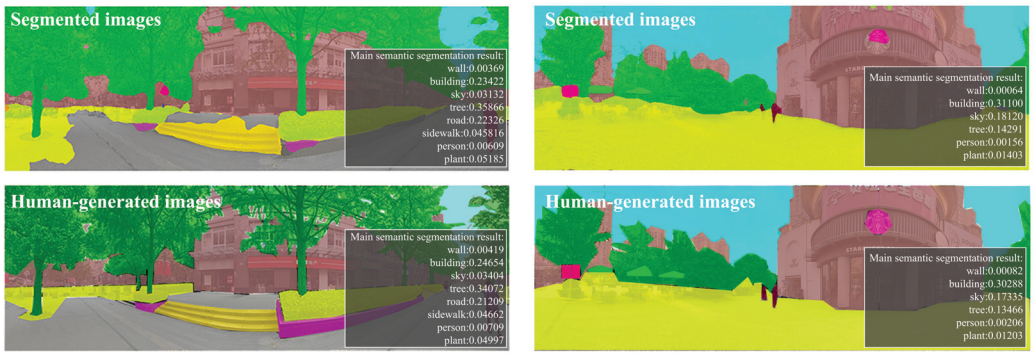

Figure 6. Example of manual verification of semantic segmentation.

3.6. Spatial and Temporal Analytical Approaches

To reduce potential scoring discrepancies, the two panoramic images captured at each sampling point were independently scored across the six perception indicators, with the results averaged to ensure accuracy and consistency. These averaged scores were linked to corresponding points and timestamps for subsequent spatial–temporal analysis.

We first computed the average emotional scores for each indicator at each time interval from 6:00 a.m. to 6:00 p.m. To analyze spatial data effectively, circular spatial units (radius = 20 m) were constructed around each sampling point. Overlapping areas were processed by averaging relevant scores, yielding comprehensive heat maps representing spatial perceptual variations throughout the study area.

Temporal trends were examined by calculating average scores across different time intervals for the entire area, identifying overall changes and general trends for the six perceptual indicators. Additionally, detailed analyses were conducted on specific street sections exhibiting distinctive temporal patterns differing from the overall average, providing supplementary explanations based on nuanced local observations.

4. Results

This section systematically examines the relationships between subjective emotional scores derived from the Place Pulse 2.0 dataset and their spatial–temporal distributions. By carefully analyzing variations across both spatial and temporal dimensions, we comprehensively captured perceived environmental quality across Golden Street. The analyses yielded essential insights to inform targeted environmental enhancement and urban design strategies.

4.1. Spatial Variation in Visual Environmental Quality on Golden Street

The spatial distribution of emotional scores, visualized in Figure 7, highlights distinct variations in environmental quality across different sections of Golden Street. Specifically, the eastern section is consistently perceived as safer and livelier compared to the western section. Scores for the "Boring" indicator remain consistently low across the entire street, reflecting a generally dynamic and engaging urban atmosphere. The "Wealthy" indicator maintains uniformly high scores throughout Golden Street, suggesting consistent perceptions of economic affluence.

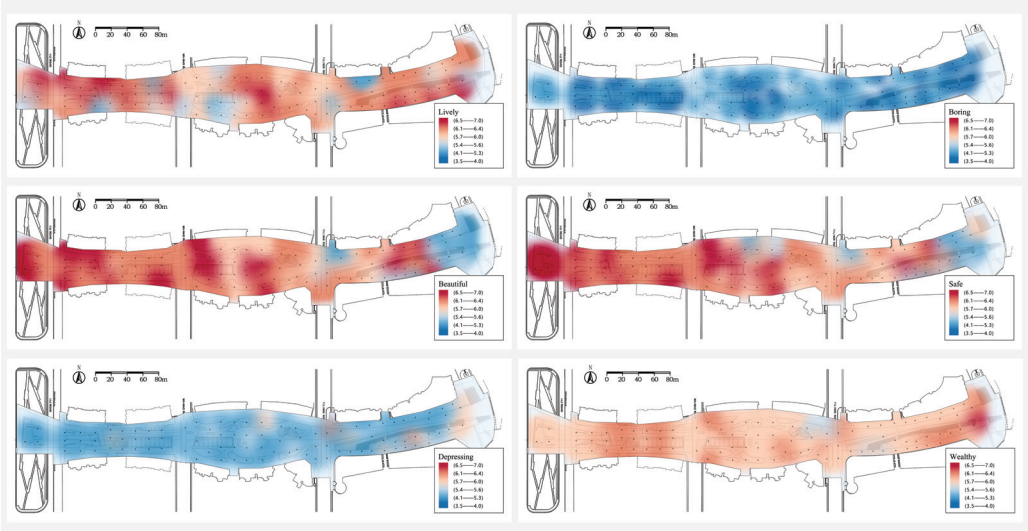

Figure 7. The hot and cold spots for each indicator in Golden Street.

A clear negative spatial correlation emerges between perceptions of visual esthetics ("Beautiful") and negative emotional evaluations ("Depressing"). Spatial clustering indicates that areas perceived as more esthetically pleasing concurrently exhibit lower scores for depression, suggesting that enhancements in visual esthetics could positively impact residents' psychological well-being. Similarly, spatial clusters also emerge between perceptions of "Wealthy" and "Lively," indicating that economically affluent areas are also perceived as more engaging.

To further validate these spatial patterns, a correlation matrix was constructed (Figure 8). The results reveal nuanced relationships between various perceptual indicators. Notably, areas perceived as "Lively" positively correlate with areas scored highly on "Beautiful" and "Wealthy," while "Safe" areas exhibit strong positive correlations with "Lively" areas. Conversely, higher "Depressing" scores consistently correspond with lower "Beautiful" and "Wealthy" perceptions, highlighting complex interplay among perceptual dimensions.

Additionally, significant negative correlations were identified between negatively evaluated indicators ("Depressing" and "Boring") and positively evaluated ones ("Lively" and "Beautiful"). Interestingly, the perception of safety ("Safe") negatively correlates with "Boring," but displays a modest positive correlation with "Depressing," alongside a moderate negative correlation with "Beautiful," suggesting intricate dynamics requiring further investigation.

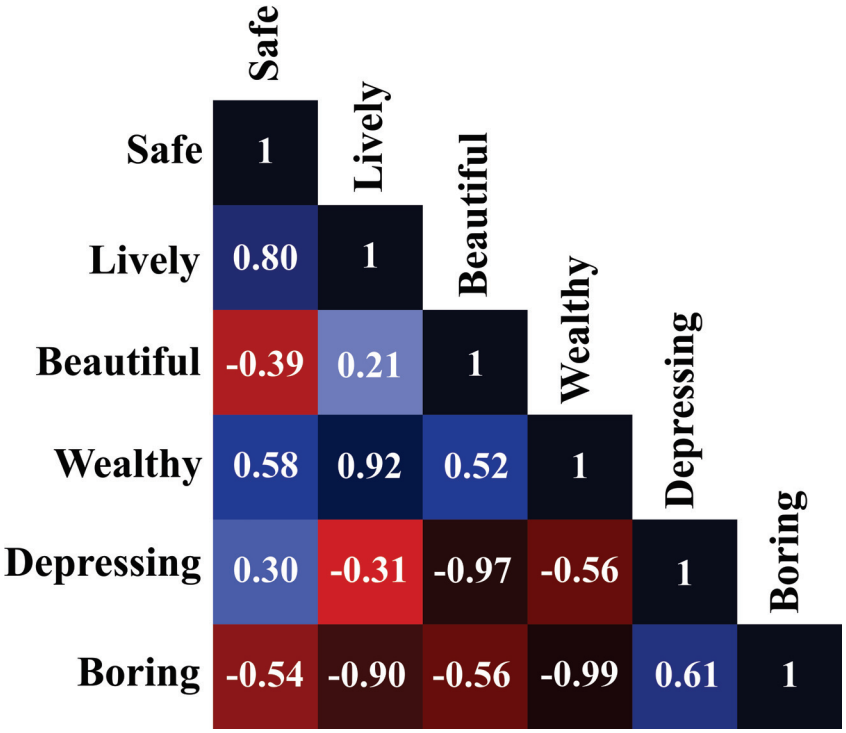

Figure 8. Correlation matrix for each perception indicator.

4.2. Spatio-Temporal Variation in Street Environmental Quality

4.2.1. Temporal Variations Across the Entire Street

Building upon the spatial analyses, the temporal dynamics of environmental perceptions were examined from 6:00 a.m. to 6:00 p.m. Figure 9. The "Wealthy" indicator remains stable throughout the day, suggesting a consistent economic perception. In contrast, other indicators ("Safe," "Lively," "Beautiful," "Depressing," and "Boring") demonstrate pronounced fluctuations, reflecting dynamic daily changes in street activity and environmental conditions.

Indicators such as "Safe," "Wealthy," and "Lively" exhibit distinctive "double-peak" patterns during the day, characterized by initial increases, subsequent decreases, and secondary increases before declining again in the evening. Correspondingly, "Boring" displays a "double-trough" pattern, achieving minimum scores (indicating higher engagement) around 9:00 a.m. and 3:00 p.m. and higher scores (indicating lower engagement) at 6:00 a.m., 12:00 p.m., and 6:00 p.m.

All positively perceived indicators—"Safe," "Lively," "Wealthy," and "Beautiful"—decline noticeably toward evening hours (around 6:00 p.m.), while negatively perceived indicators—"Depressing" and "Boring"—rise, indicating a general deterioration in perceived environmental quality as natural light diminishes.

To investigate regional temporal differences, the dispersion of emotional scores was calculated Figure 10, revealing increased perceptual divergence as evening approaches. Specifically, areas initially perceived positively during earlier times exhibit even higher positive scores later in the day, while negatively perceived areas further decline perceptually.

Individual indicators exhibit distinct temporal patterns. "Safe," "Lively," and "Boring" perceptions reach minimum dispersion at 9:00 a.m. and subsequently increase, while "Wealthy" and "Beautiful" perceptions demonstrate consistent upward trends throughout the day. "Depressing" perceptions uniquely dip at midday (12:00 p.m.) and notably rise in early morning and late afternoon.

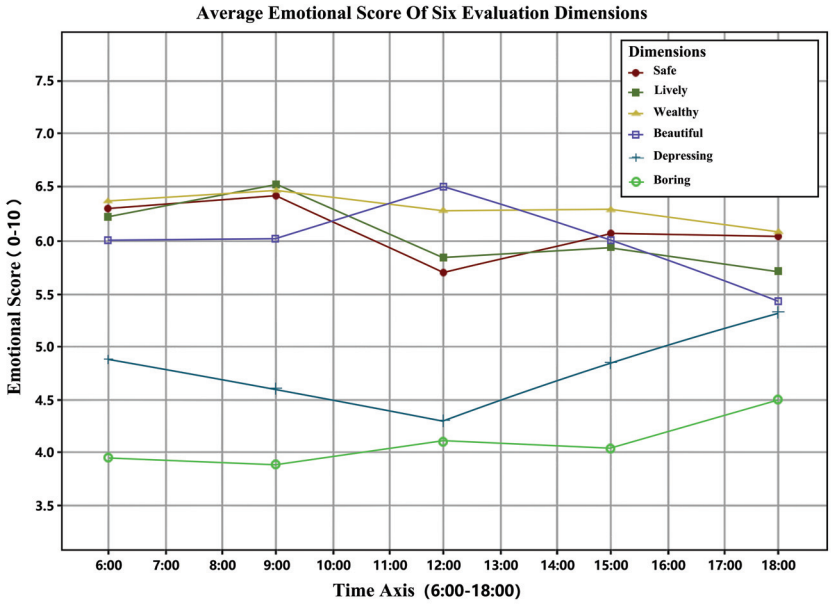

Figure 9. Average emotional scores of six evaluation dimensions.

The variability of the "Depressing" indicator is particularly pronounced, underscoring significant disparities in psychological impacts related to environmental quality. High-quality environments consistently associate with lower depressive perceptions, emphasizing the critical role environmental conditions play in urban mental health.

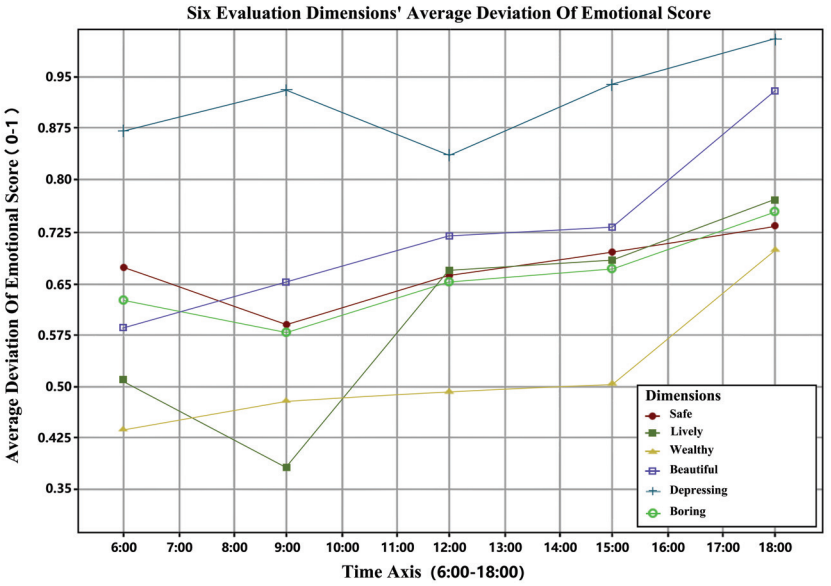

Figure 10. Six evaluation dimensions' average deviation of emotional scores.

4.2.2. Spatial Differences in Temporal Variations Among Street Sections

Detailed temporal analysis across specific street sections (east, middle, west) provides additional insights (Figure 11). Analysis of the "Wealthy" indicator indicates stability across most sections throughout the day, with only the western section showing a distinct decline at 6:00 p.m., altering the overall trend.

For the indicators "Safe" and "Lively," the middle and western sections align closely with the average trend for the entire street, whereas the eastern section consistently scores higher, particularly differing in its perceptual trends between 3:00 p.m. and 6:00 p.m. The "Beautiful" and "Boring" indicators follow similar patterns, with the eastern section

showing divergent trends during specific periods, whereas other areas largely mirror the street-wide average changes.

Regarding the "Depressing" indicator, most sections align with the average trend, except the western section, which demonstrates higher depressive scores specifically at 6:00 p.m.

Notably, emotional scores across all indicators markedly deteriorate in the western section as evening approaches (6:00 p.m.). This rapid decline coincides with reduced natural lighting, reinforcing the conclusion that lighting significantly influences perceived environmental quality.

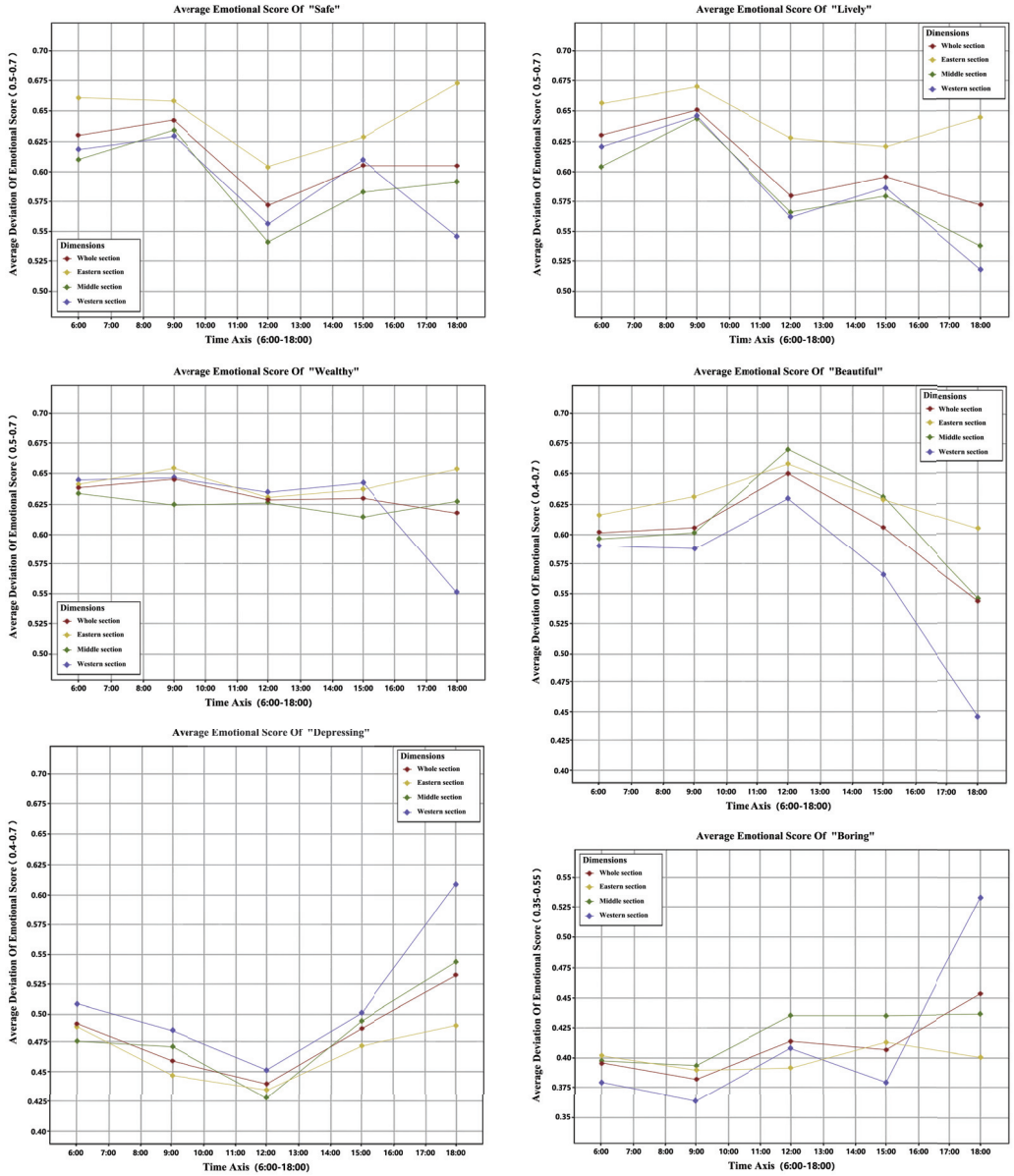

Figure 11. Average emotional scores of six evaluation dimensions across different regions.

5. Discussion

5.1. Spatio-Temporal Variation in Human Perceptions on Golden Street

Incorporating temporal dimensions through time-series analysis provides valuable insights into the dynamic changes in human perceptions throughout the day, highlighting critical periods when environmental quality diminishes, and indicating the necessity for context-specific interventions. Previous community-based studies have suggested benefi-

cial urban interventions—such as façade improvements, alley widening, additional street lighting, and the creation of pocket parks [44]—but these often lack adaptive measures accounting explicitly for spatio-temporal dynamics.

Our analysis clearly reveals distinct spatio-temporal variations in perceived environmental quality along Golden Street (Figure 12). Spatially, the eastern section is consistently perceived as safer, livelier, and more esthetically pleasing, whereas the western section generally exhibits poorer emotional scores. Prior research indicates that semi-private spaces (e.g., low walls, steps, front yards) can enhance residents' sense of security in adjacent public areas, provided these boundaries allow visual permeability and social interaction. Conversely, enclosed high walls tend to produce discomfort and insecurity [45]. These principles align with our observations on Golden Street, where the eastern section features permeable spatial boundaries through steps, low walls, and vegetation, facilitating visual connectivity and comfort. However, in the central section, enclosed high walls associated with stage designs negatively affect perceptions. In the western section, sparse vegetation coverage, weaker boundary definitions, and open views toward adjacent highways result in ambiguous spatial boundaries, contributing to lower emotional scores in safety, liveliness, and esthetics. To mitigate these issues, urban designers should consider enhancing vegetation coverage and clarifying spatial boundaries, particularly in the western section.

The sense of spatial boundary has been shown to vary significantly between day and night, as clear visibility becomes particularly critical during evening hours when ambiguous boundaries exacerbate feelings of insecurity [46]. Therefore, the design of spatial boundaries must adapt to temporal variations, emphasizing nighttime design strategies. Effective nighttime lighting emerges as a particularly crucial factor. Previous studies suggest inadequate artificial lighting typically correlates with higher crime rates and reduced perceived safety [47]. This pattern corresponds strongly with our findings for Golden Street's western section, where insufficient lighting infrastructure in open squares contributes to perceptual deterioration during evening hours. Consequently, developing a comprehensive nighttime lighting strategy could significantly enhance perceived safety, liveliness, and esthetic quality in this area.

Besides lighting, a clear and orderly layout—such as a coherent road network, continuous street interfaces, and identifiable spatial nodes—is essential for improving street environmental quality [46]. A well-organized spatial structure reduces ambiguity and uncertainty, ensuring clear visibility and facilitating activity guidance, thereby enhancing the perceived safety and attractiveness of street environments [45].

Interestingly, our study identifies a negative correlation between perceptions of "Safe" and "Beautiful," contrasting with some existing research that typically emphasizes positive associations between esthetic quality and perceived safety. Previous studies frequently suggest that esthetic enhancements (e.g., increased greenery, tidy building façades) positively impact perceived safety [48]. However, our findings indicate a more nuanced relationship that warrants further investigation, particularly within the unique contexts of pedestrian-oriented streets.

Previous research in historical districts notes that esthetic preservation measures sometimes inadvertently obscure modern security features (e.g., surveillance cameras), thereby reducing perceived safety [49]. Similarly, extensive vegetation, while visually appealing, can obstruct sightlines and compromise perceived safety [50]. On Golden Street, extensive recreational spaces and dense vegetation enhance esthetic appeal but potentially obscure security infrastructure, contributing to the negative correlation observed. Balancing esthetic quality and perceived safety thus necessitates carefully calibrating the vegetation coverage and visibility of security features [51].



Figure 12. Examples of SVI in spatio-temporal variation.

5.2. Implications for High-Quality Living Streets

Living streets, serving as vital public spaces integrated closely with daily routines, require particular attention in urban design compared to ordinary traffic-dominated roads. However, accurately assessing and quantifying their environmental quality poses methodological challenges, hindering the development of evidence-based renewal strategies. Addressing this challenge, our study introduces a novel methodological approach integrating time-series street view imagery (SVI) with deep learning techniques, enabling the systematic, large-scale, longitudinal assessment of environmental quality.

Through our case study of Golden Street, this method proved effective in objectively and comprehensively evaluating living street environments, generating robust scientific data to support urban design and renewal interventions. Empirical findings reveal significant spatio-temporal variations in environmental quality, elucidating general dynamic patterns and identifying critical influencing factors—particularly spatial boundary clarity and nighttime lighting infrastructure. These insights offer practical guidance for subsequent street improvement efforts, highlighting the importance of context-specific and temporally adaptive urban design strategies.

5.3. Limitations and Future Research Directions

5.3.1. Limitations of the Place Pulse 2.0 Dataset

Our analysis utilized the publicly available Place Pulse 2.0 dataset, which provides extensive global street view imagery annotated through crowdsourced comparisons. Despite its broad geographic coverage and substantial size, this dataset lacks detailed demographic information about participants (e.g., age, gender, cultural background), potentially introducing biases into perceptual assessments [52]. Furthermore, inherent limitations in the precision of deep learning models trained on this dataset may constrain the generalizability and interpretive depth of this study's findings.

While our research achieved relatively objective results regarding street environmental quality across six indicators through semantic segmentation and the Place Pulse 2.0 dataset, discrepancies still exist between actual street conditions and subjective perceptions. These differences may stem from multiple factors. Previous studies have demonstrated that urban elements such as road network accessibility, green space density, mixed-use land development, residential convenience, housing prices, the nighttime lighting index, and

population density all contribute to the mismatch between perceived street environments and their actual quality [53].

Nevertheless, the primary contribution of our research remains valid—the integration of advanced deep learning and time-series SVI analysis to quantify urban environmental perceptions systematically. Future studies could enhance the robustness and applicability of these methods by integrating demographic factors explicitly and refining deep learning models through further training and validation.

5.3.2. Contextual Generalizability

The manual data acquisition method employed, necessitated by the pedestrian-only nature of Golden Street, presents limitations regarding the scalability and generalizability of this study's findings. Variations in demographic profiles, street usage patterns, and urban morphology could significantly influence perceptual outcomes when applied to different urban contexts [13]. Consequently, results derived from Golden Street might not seamlessly extend to streets with substantially different physical configurations or demographic compositions.

Additionally, environmental perceptions significantly vary with weather conditions [54,55], a factor not considered in this single-day temporal scope. Therefore, further research incorporating a broader range of temporal scales and environmental conditions would enhance the comprehensiveness and applicability of the results.

Despite these limitations, this study provides valuable insights into urban street perceptions, emphasizing the necessity of context-sensitive analyses for informing urban design interventions.

5.3.3. Potential Future Analyses

This study highlights intricate relationships among subjective environmental quality indicators and their spatio-temporal variations, providing a solid foundation for future research. Further studies could refine environmental quality indicators into more granular urban design elements—such as seating configurations, signage, greenery types and density—to better understand their impacts. Prior research indicates that seating and greenery interactions intensify during evening hours, significantly influencing street vitality and social interactions [56].

Moreover, architectural elements such as building heights, facade proportions, and color schemes substantially affect perceived environmental quality. Wu et al. (2025) indicated that streetscapes with certain building ratios (BR > 60%) and roof ratios (RR > 30%) could appear fragmented or evoke depressive feelings [57]. Future research could investigate these architectural dimensions more explicitly, deepening our understanding and enabling targeted urban interventions to enhance street environmental quality effectively.

6. Conclusions

Effectively monitoring and quantitatively evaluating spatio-temporal variations in the environmental quality of pedestrian-oriented streets remains a significant methodological challenge in urban studies. Although deep learning methodologies have increasingly matured, their application in time-series analyses—particularly within pedestrian-oriented urban contexts—remains limited. To address this gap, this study integrates advanced deep learning techniques with time-series street view imagery (SVI) to systematically evaluate environmental quality variations along Golden Street, a representative living street in Shanghai.

This research comprehensively explores street environmental quality, systematically analyzing spatial variations across different locations at specific times and temporal variations at fixed locations throughout a single day. The following key findings emerged from the analyses.

Spatially, the eastern section of Golden Street is consistently perceived as safer, livelier, and more esthetically pleasing compared to the western section. The entire street exhibited consistently low scores for "Boring" and uniformly high scores for "Wealthy," indicating an engaging and economically vibrant atmosphere overall. Correlation analysis revealed a complex interplay among perceptual indicators: positive indicators ("Lively," "Beautiful," and "Wealthy") demonstrated strong negative correlations with negative indicators ("Depressing" and "Boring"). Notably, the "Safe" indicator exhibited a mild negative correlation with "Beautiful" and a slight positive correlation with "Depressing," highlighting intricate relationships requiring nuanced urban design considerations.

Temporally, perceptions of "Wealthy" remained relatively stable across the day, whereas indicators such as "Safe," "Lively," "Beautiful," "Depressing," and "Boring" displayed pronounced fluctuations. Indicators "Safe," "Wealthy," and "Lively" exhibited characteristic "double-peak" patterns, reflecting typical rhythms of pedestrian activity and street vibrancy. Conversely, the "Boring" indicator exhibited a "double-trough" pattern, correlating inversely with peak periods of pedestrian engagement. Significantly, all positive perceptual indicators decreased towards the evening (around 6:00 p.m.), particularly in the western section, coinciding with diminishing natural light and exacerbating perceptions of insecurity and depression. Analysis indicated boundary clarity and nighttime lighting as critical factors influencing these spatio-temporal dynamics, suggesting temporally adaptive design interventions.

Through empirical validation, this study confirms the efficacy of integrating time-series SVI and deep learning methods in systematically evaluating pedestrian street environmental quality. Insights derived from this research enhance our understanding of complex perceptual dynamics and provide robust guidance for targeted urban planning and renewal interventions. Specifically, urban planners and policymakers can leverage these findings to implement context-sensitive, temporally adaptive improvements, ultimately contributing to more livable, engaging, and psychologically supportive urban streetscapes.

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References

1. Schneider, A.; Friedl, M.A.; Potere, D. Mapping global urban areas using MODIS 500-m data: New methods and datasets based on 'urban ecoregions'. *Remote Sens. Environ.* **2010**, *114*, 1733–1746. [CrossRef]
2. Lu, Y.; Sarkar, C.; Xiao, Y. The effect of street-level greenery on walking behavior: Evidence from Hong Kong. *Soc. Sci. Med.* **2018**, *208*, 41–49. [CrossRef]
3. Saelens, B.E.; Handy, S.L. Built environment correlates of walking: A review. *Med. Sci. Sport. Exerc.* **2008**, *40*, S550. [CrossRef]
4. Gutman, R. The social function of the built environment. In *The Mutual Interaction of People and Their Built Environment*; De Gruyter Mouton: Berlin, Germany; New York, NY, USA, 1976; p. 37.
5. Allocated, L.; Core, C. *Streets as Public Spaces and Drivers of Urban Prosperity*; UN-HABITAT: Nairobi, Kenya, 2013; p. 108.
6. Wang, J.; Chow, Y.S.; Biljecki, F. Insights in a city through the eyes of Airbnb reviews: Sensing urban characteristics from homestay guest experiences. *Cities* **2023**, *140*, 104399. [CrossRef]
7. Liu, L.; Silva, E.A.; Wu, C.; Wang, H. A machine learning-based method for the large-scale evaluation of the qualities of the urban environment. *Comput. Environ. Urban Syst.* **2017**, *65*, 113–125. [CrossRef]
8. Biljecki, F.; Ito, K. Street view imagery in urban analytics and GIS: A review. *Landsc. Urban Plan.* **2021**, *215*, 104217. [CrossRef]

9. Jeon, J.; Woo, A. Deep learning analysis of street panorama images to evaluate the streetscape walkability of neighborhoods for subsidized families in Seoul, Korea. *Landsc. Urban Plan.* **2023**, *230*, 104631. [CrossRef]
10. Huang, Z.; Du, X. Assessment and determinants of residential satisfaction with public housing in Hangzhou, China. *Habitat Int.* **2015**, *47*, 218–230. [CrossRef]
11. Zhang, F.; Zhou, B.; Liu, L.; Liu, Y.; Fung, H.H.; Lin, H.; Ratti, C. Measuring human perceptions of a large-scale urban region using machine learning. *Landsc. Urban Plan.* **2018**, *180*, 148–160. [CrossRef]
12. Liu, Z.; Ma, L. Residential experiences and satisfaction of public housing renters in Beijing, China: A before-after relocation assessment. *Cities* **2021**, *113*, 103148. [CrossRef]
13. An, D.; Liu, Y.; Huang, Y. The Influence of Street Components on Age Diversity: A Case Study on a Living Street in Shanghai. *Sustainability* **2023**, *15*, 10493. [CrossRef]
14. Wang, Z.; Ito, K.; Biljecki, F. Assessing the equity and evolution of urban visual perceptual quality with time series street view imagery. *Cities* **2024**, *145*, 104704. [CrossRef]
15. Kang, Y.; Zhang, F.; Gao, S.; Lin, H.; Liu, Y. A review of urban physical environment sensing using street view imagery in public health studies. *Ann. GIS* **2020**, *26*, 261–275. [CrossRef]
16. Goel, R.; Garcia, L.M.; Goodman, A.; Johnson, R.; Aldred, R.; Murugesan, M.; Brage, S.; Bhalla, K.; Woodcock, J. Estimating city-level travel patterns using street imagery: A case study of using Google Street View in Britain. *PLoS ONE* **2018**, *13*, e0196521. [CrossRef]
17. Chen, S.; Biljecki, F. Automatic assessment of public open spaces using street view imagery. *Cities* **2023**, *137*, 104329. [CrossRef]
18. Helbich, M.; Yao, Y.; Liu, Y.; Zhang, J.; Liu, P.; Wang, R. Using deep learning to examine street view green and blue spaces and their associations with geriatric depression in Beijing, China. *Environ. Int.* **2019**, *126*, 107–117. [CrossRef] [PubMed]
19. Dubey, A.; Naik, N.; Parikh, D.; Raskar, R.; Hidalgo, C.A. Deep learning the city: Quantifying urban perception at a global scale. In Proceedings of the Computer Vision–ECCV 2016: 14th European Conference, Amsterdam, The Netherlands, 11–14 October 2016; Proceedings, Part I 14; Springer: Berlin/Heidelberg, Germany, 2016; pp. 196–212.
20. Dadvand, P.; Bartoll, X.; Basagaña, X.; Dalmau-Bueno, A.; Martinez, D.; Ambros, A.; Cirach, M.; Triguero-Mas, M.; Gascon, M.; Borrell, C.; et al. Green spaces and general health: Roles of mental health status, social support, and physical activity. *Environ. Int.* **2016**, *91*, 161–167. [CrossRef] [PubMed]
21. Wei, J.; Yue, W.; Li, M.; Gao, J. Mapping human perception of urban landscape from street-view images: A deep-learning approach. *Int. J. Appl. Earth Obs. Geoinf.* **2022**, *112*, 102886. [CrossRef]
22. Zhang, F.; Fan, Z.; Kang, Y.; Hu, Y.; Ratti, C. "Perception bias": Deciphering a mismatch between urban crime and perception of safety. *Landsc. Urban Plan.* **2021**, *207*, 104003. [CrossRef]
23. Long, Y.; Ye, Y. Measuring human-scale urban form and its performance. *Landsc. Urban Plan.* **2019**, *191*, 103612. [CrossRef] [PubMed]
24. Nasar, J.L. Perception, cognition, and evaluation of urban places. In *Public Places and Spaces*; Springer: Berlin/Heidelberg, Germany, 1989; pp. 31–56.
25. Bonaiuto, M.; Fornara, F. Residential satisfaction and perceived urban quality. *Encycl. Appl. Psychol.* **2004**, *3*, 267–272.
26. Smardon, R.C. Perception and aesthetics of the urban environment: Review of the role of vegetation. *Landsc. Urban Plan.* **1988**, *15*, 85–106. [CrossRef]
27. Liu, K.; Zhang, L.; Tsou, S.; Wang, L.; Hu, Y.; Yang, K. Exploring the Complex Association Between Urban Built Environment, Sociodemographic Characteristics and Crime: Evidence from Washington, DC. *Land* **2024**, *13*, 1886. [CrossRef]
28. Gebru, T.; Krause, J.; Wang, Y.; Chen, D.; Deng, J.; Aiden, E.L.; Li, F. Using deep learning and Google Street View to estimate the demographic makeup of neighborhoods across the United States. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 13108–13113. [CrossRef]
29. Li, M.; Sheng, H.; Irvin, J.; Chung, H.; Ying, A.; Sun, T.; Ng, A.Y.; Rodriguez, D.A. Marked crosswalks in US transit-oriented station areas, 2007–2020: A computer vision approach using street view imagery. *Environ. Plan. B Urban Anal. City Sci.* **2023**, *50*, 350–369. [CrossRef]
30. Liang, X.; Zhao, T.; Biljecki, F. Revealing spatio-temporal evolution of urban visual environments with street view imagery. *Landsc. Urban Plan.* **2023**, *237*, 104802. [CrossRef]
31. Rui, J. Measuring streetscape perceptions from driveways and sidewalks to inform pedestrian-oriented street renewal in Düsseldorf. *Cities* **2023**, *141*, 104472. [CrossRef]
32. Li, X.; Zhang, C.; Li, W.; Ricard, R.; Meng, Q.; Zhang, W. Assessing street-level urban greenery using Google Street View and a modified green view index. *Urban For. Urban Green.* **2015**, *14*, 675–685. [CrossRef]
33. Naik, N.; Philipoom, J.; Raskar, R.; Hidalgo, C. Streetscore-predicting the perceived safety of one million streetscapes. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition Workshops, Columbus, OH, USA, 23–28 June 2014; pp. 779–785.
34. Bradley, R.A.; Terry, M.E. Rank analysis of incomplete block designs: I. The method of paired comparisons. *Biometrika* **1952**, *39*, 324–345. [CrossRef]

35. Alexander, C. *A Pattern Language: Towns, Buildings, Construction*; Oxford University Press: Oxford, UK, 1977.
36. Causeur, D.; Husson, F. A 2-dimensional extension of the Bradley–Terry model for paired comparisons. *J. Stat. Plan. Inference* **2005**, *135*, 245–259. [CrossRef]
37. Chen, L.C.; Zhu, Y.; Papandreou, G.; Schroff, F.; Adam, H. Encoder-decoder with atrous separable convolution for semantic image segmentation. In Proceedings of the European Conference on Computer Vision (ECCV), Munich, Germany, 8–14 September 2018; pp. 801–818.
38. Cordts, M.; Omran, M.; Ramos, S.; Rehfeld, T.; Enzweiler, M.; Benenson, R.; Franke, U.; Roth, S.; Schiele, B. The cityscapes dataset for semantic urban scene understanding. In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, Las Vegas, NV, USA, 27–30 June 2016; pp. 3213–3223.
39. Ren, Z.; Wang, L.; Song, T.; Li, Y.; Zhang, J.; Zhao, F. Enhancing Road Scene Segmentation with an Optimized DeepLabV3+. *IEEE Access* **2024**, *12*, 197748–197765 [CrossRef]
40. Qin, J.; Xu, C.; Ai, Y.; Zhang, H.; Cheng, Y. Research on Semantic Segmentation Algorithm for Autonomous Driving Based on Improved DeepLabv3+. In *Artificial Intelligence in China, Proceedings of the International Conference on Artificial Intelligence in China, Wuhan, China, 18–20 November 2023*; Springer: Singapore, 2023; pp. 107–117.
41. Chen, L.C.; Papandreou, G.; Kokkinos, I.; Murphy, K.; Yuille, A.L. Deeplab: Semantic image segmentation with deep convolutional nets, atrous convolution, and fully connected crfs. *IEEE Trans. Pattern Anal. Mach. Intell.* **2017**, *40*, 834–848. [CrossRef]
42. Hadinata, P.N.; Simanta, D.; Eddy, L.; Nagai, K. Crack detection on concrete surfaces using deep encoder-decoder convolutional neural network: A comparison study between U-Net and DeepLabV3+. *J. Civ. Eng. Forum* **2021**, *7*, 323–334. [CrossRef]
43. Liu, Y.; Tian, Y.; Chen, Y.; Liu, F.; Belagiannis, V.; Carneiro, G. Perturbed and strict mean teachers for semi-supervised semantic segmentation. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, New Orleans, LA, USA, 18–24 June 2022; pp. 4258–4267.
44. Jiang, B.; Mak, C.N.S.; Zhong, H.; Larsen, L.; Webster, C.J. From broken windows to perceived routine activities: Examining impacts of environmental interventions on perceived safety of urban alleys. *Front. Psychol.* **2018**, *9*, 2450. [CrossRef]
45. Newman, O. *Defensible Space: Crime Prevention Through Urban Design*; Collier Books: New York, NY, USA, 1973.
46. Lynch, K. *The Image of the City*; MIT Press: Cambridge, MA, USA, 1964.
47. Cozens, P.M.; Saville, G.; Hillier, D. Crime prevention through environmental design (CPTED): A review and modern bibliography. *Prop. Manag.* **2005**, *23*, 328–356. [CrossRef]
48. Nasar, J.L. Visual preferences in urban street scenes: A cross-cultural comparison between Japan and the United States. *J. Cross-Cult. Psychol.* **1984**, *15*, 79–93. [CrossRef]
49. Fuller, M.; Moore, R. *An Analysis of Jane Jacobs's the Death and Life of Great American Cities*; Macat Library: London, UK, 2017.
50. Jansson, M.; Fors, H.; Lindgren, T.; Wiström, B. Perceived personal safety in relation to urban woodland vegetation–A review. *Urban For. Urban Green.* **2013**, *12*, 127–133. [CrossRef]
51. Ristea, A.; Leitner, M.; Resch, B.; Stratmann, J. Applying spatial video geonarratives and physiological measurements to explore perceived safety in Baton Rouge, Louisiana. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1284. [CrossRef] [PubMed]
52. Kang, Y.; Abraham, J.; Ceccato, V.; Duarte, F.; Gao, S.; Ljungqvist, L.; Zhang, F.; Näsman, P.; Ratti, C. Assessing differences in safety perceptions using GeoAI and survey across neighbourhoods in Stockholm, Sweden. *Landsc. Urban Plan.* **2023**, *236*, 104768. [CrossRef]
53. Ma, S.; Wang, B.; Liu, W.; Zhou, H.; Wang, Y.; Li, S. Assessment of street space quality and subjective well-being mismatch and its impact, using multi-source big data. *Cities* **2024**, *147*, 104797. [CrossRef]
54. Chiang, Y.C.; Liu, H.H.; Li, D.; Ho, L.C. Quantification through deep learning of sky view factor and greenery on urban streets during hot and cool seasons. *Landsc. Urban Plan.* **2023**, *232*, 104679. [CrossRef]
55. Han, Y.; Zhong, T.; Yeh, A.G.; Zhong, X.; Chen, M.; Lü, G. Mapping seasonal changes of street greenery using multi-temporal street-view images. *Sustain. Cities Soc.* **2023**, *92*, 104498. [CrossRef]
56. Lian, H.; Li, X.; Zhou, W.; Zhang, J.; Li, H. Pedestrian vitality characteristics in pedestrianized commercial streets-considering temporal, spatial, and built environment factors. *Front. Archit. Res.* **2025**, *14*, 630–653. [CrossRef]
57. Wu, T.; Chen, Z.; Li, S.; Xing, P.; Wei, R.; Meng, X.; Zhao, J.; Wu, Z.; Qiao, R. Decoupling Urban Street Attractiveness: An Ensemble Learning Analysis of Color and Visual Element Contributions. *Land* **2025**, *14*, 979. [CrossRef]

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Residents' Perceptions of Informal Green Spaces in High-Density Cities: Urban Land Governance Implications from Taipei

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Abstract: In high-density and land-scarce urban environments such as Taipei—a typical example of compact development in East Asia—informal green spaces (IGSs)—defined as unmanaged or unplanned vegetated urban areas such as vacant lots, street verges, and railway margins—play a growing role in urban environmental and social dynamics. This study explores residents' perceptions of IGSs and examines how these spaces contribute to urban sustainability and land governance. Using a mixed-methods approach that combines the literature review, field observations, and a structured public opinion survey in Taipei's Wenshan District, the study identifies key perceived benefits and drawbacks of IGSs. Findings show that residents highly value IGSs for enhancing urban greenery, offering recreational opportunities, and promoting physical and mental health. However, concerns persist regarding safety, sanitation, and maintenance—particularly fears of waste accumulation, mosquito breeding, and risks to children. The results highlight the dual nature of IGSs as both vital ecological assets and potential sources of urban disorder. These insights underscore the need for inclusive, community-based governance models that can transform IGSs into legitimate components of green infrastructure. The study contributes to emerging discussions on adaptive urban land governance by proposing that informal spaces be strategically integrated into urban planning frameworks to enhance environmental equity, resilience, and citizen well-being.

Keywords: urban planning; public participation; land use; urban land governance; ecosystem services; community engagement; high-density cities; compact urban development

1. Introduction

In rapidly urbanizing and land-scarce cities, such as those in East Asia, urban land resources are increasingly under pressure from high-density development, real estate speculation, and the prioritization of economic over ecological functions [1,2]. As a result, the provision of formal green infrastructure often falls short of national or international standards, especially in compact cities like Taipei [1]. This situation has intensified the search for alternative land resources that can support ecological, social, and recreational functions. One such underexplored resource is informal green space (IGS)—including vacant lots, brownfields, roadside verges, utility corridors, and unmanaged or spontaneous vegetated areas [3–7].

IGSs refer to vegetated areas within urban environments that are not formally designated, planned, or maintained as public green spaces. These include vacant lots, roadside

verges, railway embankments, riverbanks, and other unmanaged or spontaneous green patches that arise due to regulatory, spatial, or developmental gaps. Although often overlooked in formal planning processes, IGSs provide a range of ecological, recreational, and cultural functions. As Rupprecht and Byrne [3] note, IGSs are frequently considered "leftover" or marginal urban spaces, yet they play a significant role in residents' everyday interactions with nature.

Building on the study by Kim et al. [1] in Ichikawa City, which examined residents' perceptions of IGSs in a suburban Japanese context, this study investigates similar perceptions in a dense inner-city district in Taipei. While both cities are situated in East Asia, their contrasting spatial characteristics, land use intensity, and socio-political contexts offer a valuable comparative perspective. This study thus seeks to extend the understanding of IGSs' perception into a high-density, inner-urban environment.

IGSs are not formally designated or maintained as public green spaces but are often used by residents for walking, jogging, gardening, and informal social gatherings [1,8,9]. These spaces frequently emerge from urban voids or are shaped through grassroots or community efforts. Although typically overlooked in urban planning, IGSs provide a wide range of ecosystem services, including temperature regulation [7,10–13], biodiversity enhancement [14], and recreational opportunities [8,15]. Importantly, IGSs can serve to reduce inequalities in access to green spaces for marginalized groups such as children and the elderly [16], while also supporting socio-cultural values [17].

However, the benefits of IGSs coexist with concerns related to safety, cleanliness, social conflict, and governance ambiguity [6,18]. Poorly maintained or perceived unsafe spaces may negatively affect residents' well-being, particularly in disadvantaged neighborhoods [5,19]. Furthermore, IGSs can become inaccessible due to privatization or lack of community engagement, as noted in recent critiques of housing developments that incorporate but restrict access to green areas [16].

There is increasing evidence that IGSs contribute to both mental and physical health outcomes, including reduced stress, improved cardiovascular health, and increased physical activity [1,20–24]. The more naturalistic qualities of IGSs often foster stronger restorative experiences than manicured parks [25,26]. At the same time, urban green spaces and IGSs can function synergistically, offering a complementary system of structured and spontaneous recreational environments [15,25,27].

Despite their potential, residents' perceptions and evaluations of IGSs remain understudied, particularly in Asian cities where land scarcity and high development intensity create unique conditions for informal green space to emerge and function [1,2,26]. Perceptions of IGSs are influenced by various factors, including safety, accessibility, esthetics, maintenance, and personal or cultural preferences [23,28]. While some residents may prefer wild and spontaneous spaces, others may favor more designed or controlled environments [5,20].

Citizen participation plays a critical role in shaping perceptions and the success of IGSs. Community engagement in gardening or co-maintenance initiatives can foster stewardship and increase perceived value [1,17,22]. Different IGS maintenance regimes—ranging from non-intervention to periodic intervention—can also influence their ecological contribution and social acceptance [7,8,23].

In light of these considerations, IGSs should be reframed not as leftover or failed urban space but rather as latent land resources capable of enhancing socio-ecological resilience and supporting adaptive land governance [2,6]. This is especially pertinent for cities experiencing demographic shifts or undergoing urban shrinkage, where IGSs can support land use transitions and sustainable reuse strategies [14].

For example, Taipei City provides approximately 5.36 m^2 of public green space per person, significantly lower than the World Health Organization's recommended minimum of 9 m^2 and far below UN-Habitat's ideal standard of 15 m^2 per capita. According to the Taipei City Government's statistics, less than 3% of the total urban land area is allocated to parkland, reflecting the city's limited capacity to develop additional formal green infrastructure. This spatial limitation underscores the importance of exploring alternative green provisions—such as IGSs—to meet residents' recreational and ecological needs under conditions of spatial constraint. This study situates IGSs within the broader challenges of green space governance in high-density cities. Such contexts—characterized by limited per capita open space, high land values, and rapid infill development—create distinctive pressures on both formal and informal green infrastructures. As such, understanding how residents engage with IGSs in a city like Taipei can yield policy-relevant insights for other compact urban environments. The purpose of this study is to explore the current state of IGSs in Taipei City and examine how residents perceive, use, and evaluate these spaces. Through a mixed-methods approach—combining the literature review, questionnaire surveys, field observations, and in-depth interviews—we aim to address the following research questions:

- How do urban residents perceive and use IGSs in high-density cities?
- What functions and values do they associate with these spaces?
- How might these perceptions inform future land governance strategies and green space planning?

By foregrounding public attitudes toward IGSs, this study contributes to the growing discourse on adaptive land management, participatory planning, and the integration of informal spaces into sustainable urban land use systems. To further theorize the dual character of IGSs as both opportunity and challenge, this study draws on Simandan's concept of "the wise stance", which interprets wisdom as a form of balancing competing urban values—between ecological spontaneity and safety concerns, or between informal uses and formal planning [29]. This conceptual lens helps frame IGSs not simply as neglected spaces, but as sites of negotiated cohabitation.

Moreover, urban wildscapes—often found in the form of post-industrial or marginal spaces—have been critically examined by scholars such as Whatmore in her theory of Hybrid Geographies, which challenges binary distinctions between nature and culture [30]. Gandy's recent work Natura Urbana [31] further situates these spaces within urban political ecology, emphasizing their latent capacity to reflect social imaginaries and contested ecological futures.

2. Materials and Methods

2.1. Research Area

The study was conducted in Wenshan District of Taipei City, a dense urban area known for its proximity to hills and waterways, yet also constrained by limited availability of formal green spaces. While Taipei promotes mixed-use development and has invested in formal parks such as Daan Forest Park and Riverside Park, many residents engage with IGSs—including vacant lots, roadside verges, and rooftop gardens—for recreational and ecological purposes. These spaces often exist outside formal planning systems, making them ideal for examining resident perceptions under conditions of limited green infrastructure provision. The selection of Wenshan District was based on its diverse land use types, socio-demographic mix, and visible presence of IGSs. To enhance the spatial understanding of the fieldwork area, a map of the identified IGSs is provided in Figures 1 and 2. This visual contextualization helps illustrate the distribution and variety of green parcels included in the study.



Figure 1. Experimental site map of Wenshan District, Taipei City.



Figure 2. Informal Green Spaces (IGSs) selected for field observation and survey in Wenshan District, Taipei. The map shows the spatial distribution of vacant lots, roadside green strips, and underutilized parcels identified through field visits and community input.

2.1.1. Mixed-Use Development and Transportation

Taipei City has embraced mixed-use development, which combines residential, commercial, and office spaces within the same building or neighborhood. This encourages sustainable living and reduces the need for long commutes. Additionally, mixed-use development promotes walkability, as residents have easy access to amenities and services within their neighborhood. Taipei City has developed an extensive public transportation

system, which includes buses, subways, and a high-speed rail system. This transportation network provides residents and visitors with efficient and affordable modes of transportation, reducing traffic congestion and air pollution. In addition, the city has implemented a bike-sharing program that encourages the use of sustainable and healthy modes of transportation.

2.1.2. Green Spaces

Taipei City is known for its numerous green spaces, which provide residents and visitors with opportunities for recreation, relaxation, and connection with nature. The most popular green spaces in Taipei such as the following: Daan Forest Park, Taipei Riverside Park, and Taipei Botanical Garden. Overall, Taipei City's green spaces are an important part of the city's culture and identity, providing residents and visitors with opportunities to connect with nature and enjoy the outdoors. IGSs in Taipei City refer to areas that are not designated as official parks or public green spaces but still serve as important recreational and social spaces for residents. These areas can take many forms, such as community gardens, vacant lots, and roadside plantings.

2.1.3. IGSs

One notable example of IGSs in Taipei City is the rooftop gardens that have become increasingly popular in recent years. Residents often establish rooftop gardens using containers and improvised materials to cultivate fruits, vegetables, and ornamental plants. Not only do these gardens provide residents with access to fresh produce, but they also help to mitigate the urban heat-island effect and improve air quality.

Another type of IGSs in Taipei City are the so-called "pocket parks". These are small, often hidden green spaces that can be found throughout the city, such as in alleyways or on the edges of neighborhoods. These parks often feature benches, plants, and other amenities and serve as important gathering places for local residents. One challenge with IGSs in Taipei City is that they may not receive the same level of maintenance and care as official parks, which can lead to issues with litter and overgrowth. However, these spaces also offer a sense of community ownership and engagement, as residents take on the responsibility of maintaining and caring for them. Overall, IGSs in Taipei City play an important role in providing residents with access to greenery and nature, as well as fostering a sense of community and connection to the urban environment.

Taipei City's urban planning efforts are focused on creating a livable, sustainable, and resilient city for its residents and visitors. Through the implementation of an extensive public transportation system, the creation of formal and IGSs, and the adoption of mixed-use development, Taipei City is addressing the challenges of population growth and the need for sustainable development. These efforts demonstrate Taipei City's commitment to creating a more livable and sustainable urban environment.

2.2. Classification of IGSs

Compared to formal green spaces—such as urban parks, botanical gardens, and designated green corridors—which are officially planned, funded, and maintained by public authorities, IGSs lack formal designation and institutional management. While formal green spaces are often associated with structured recreational amenities, landscape esthetics, and strict zoning, IGSs are typically characterized by spontaneity, adaptive reuse, and marginal status in planning systems [3,16].

Despite these differences, both types contribute to urban ecosystem services, albeit in different ways. Formal green spaces are designed for predictability, safety, and social integration, while IGSs provide critical ecological functions in overlooked or residual spaces, such as supporting biodiversity, enhancing microclimates, and serving marginalized

communities [5]. Therefore, a critical distinction lies in their governance and inclusivity; IGSs often embody grassroots engagement and adaptive potential, whereas formal green spaces reflect top-down planning approaches.

The literature analysis method is a valuable research methodology that provides researchers with a comprehensive understanding of a particular field of study. By organizing, evaluating, and analyzing the relevant literature, researchers can identify key findings, theories, and methods related to a particular topic and use this information to propose further research questions and hypotheses. Overall, the literature analysis is a useful tool for researchers in a variety of fields. Through the method of the literature analysis, this study refers to the clear definition of IGSs in the relevant literature [1,3,4,6,8,32]. "Informal green space" refers to green areas in urban or peri-urban environments that are not formally recognized or planned as public parks or green spaces. These spaces can take a variety of forms, such as vacant lots, community gardens, roadside plantings, or green roofs. After referring to the relevant literature [3–5,7,8,16,20–22,24,26–28,32,33], this study concludes that there are the following types of IGSs, such as: street verge, lot, gap, railway, brownfield, waterside, structural, microsite, power line, fortification, and fallow or uncultivated land, etc.

Informal green space exists around residents' homes and is relatively accessible; the original urban ecosystem is completely preserved. Compared with managed green spaces such as parks, there are abundant natural resources; it offers a degree of spontaneity and adventure often lacking in formal parks, especially appealing to the youth. However, human beings often regard the environment that lacks management and maintenance as an unsafe space subjectively; the unbeautified natural landscape and vegetation space will increase the possibility of crime and reduce the willingness of users to go there. Therefore, IGSs have multiple functions [6,11,25].

Several studies have demonstrated that IGSs can serve as sites of social interaction, provide visual relief, and enhance perceived neighborhood quality. Kim et al. [1] categorized IGSs' types based on physical characteristics and evaluated user perceptions through a structured survey. They found that residents valued IGSs for accessibility and visual relief but expressed concerns over safety and maintenance. Their study emphasized the importance of spatial context and prior experience in shaping perception—a premise that also informs the present study. Similarly, in the context of Taipei, our study aims to explore how spatial conditions, accessibility, and past neighborhood engagement influence the perception and acceptance of IGSs.

The utilization and planning of green spaces is a common focus in urban research. Taipei City's current regulations on legal green spaces in urban planning encompass parks, sports venues, green spaces, squares, and children's playgrounds. Formal green spaces are often well-integrated into planning frameworks but face significant governance and implementation challenges—especially in ensuring accessibility, multifunctionality, and stakeholder engagement. One study, in a case study of Berlin, highlights that even in well-established formal green spaces, the integration of ecosystem services into planning faces fragmented governance, conflicting stakeholder interests, and data limitations [9]. These issues suggest that IGSs, while informally managed, may offer adaptive advantages in addressing urban sustainability gaps under constrained institutional conditions.

In the realm of academic research, the identification of green spaces is largely dependent on the researcher's objectives. Typically, green space is defined as managed areas such as parks, schools, or gardens. Informal spaces like rivers, railways, utility poles, or gaps between buildings are deemed unsafe due to a lack of regular maintenance, which results in residents being less inclined to utilize these areas. Furthermore, in the absence of green space within the living environment, some residents may spontaneously create

green space that does not conform to the planning system. In today's cities, residents may have unconsciously utilized or established IGSs to compensate for the lack of formal green spaces. Despite their scattered distribution throughout urban areas, these "IGSs" possess an inherent value that cannot be understated.

2.3. Positive and Negative Impacts of "Informal Green Space"

2.3.1. Positive Impacts of "Informal Green Space"

IGSs, also known as urban green spaces or green infrastructure, refer to areas within cities that are not designated as formal parks or gardens but still provide natural elements and ecological benefits. These spaces can include community gardens, vacant lots, street trees, pocket parks, and other small-scale green areas. While formal parks and protected areas are important, IGSs also play a significant role in enhancing the urban environment and have several positive impacts. Let us explore some of the following positive impacts, such as: biodiversity and habitat preservation, climate regulation, improved mental health and well-being, community engagement and social cohesion, and stormwater management.

Firstly, IGSs can act as valuable habitats for various plant and animal species, contributing to urban biodiversity. Some studies' results show that IGSs play an important role for biodiversity [8]. One study also found comparable ecosystem services provisioning for dust removal, cooling benefits, water storage, and biodiversity preservation in IGSs and urban parks [27]. They provide food, shelter, and nesting sites for birds, insects, and other wildlife, thereby supporting local ecosystems. These spaces often contain a diverse range of plant species, including native plants, which further enhances their ecological value.

For study ecosystem services of IGSs, after reviewing the 112 papers, one paper found three types of services that were discussed the most: habitat services, cultural services, and climate regulation services [5]. In fact, urban green spaces, both formal and informal, contribute to climate regulation by mitigating the urban heat island effect. Vegetation in IGSs absorbs and filters pollutants from the air while providing shade and reducing the surface temperature in built-up areas. This helps to cool the surrounding environment, improve air quality, and reduce energy consumption for air conditioning.

In recognition that the coming century will see a substantial majority of the world's population living in urban areas, the World Health Organization and the United Nations have developed policy frameworks and guidance, which promote the increased provision of urban green space for population health [20]. IGSs offer opportunities for relaxation, recreation, and social interaction. Access to green spaces has been linked to improved mental health outcomes, including reduced stress, anxiety, and depression. Spending time in these areas can promote physical activity, encourage social connections, and provide a sense of tranquility, which positively impacts overall well-being.

One study found that urban parks are more inclusive green places than non-urban green areas and that urban parks can promote social cohesion [34]. Moreover, IGSs often serve as gathering places for local communities, fostering a sense of belonging and social cohesion. Community gardens, for instance, bring people together around a shared interest in gardening, food production, and environmental stewardship. These spaces provide opportunities for education, skill-building, and the exchange of knowledge among community members. Nevertheless, due to various constraints and barriers, such as lack of accessibility, limited local knowledge or acceptance, and the cultural services of IGSs, especially those related to recreation, are not fully exploited. The similar conclusion was reached by a study where people did not use these spaces for recreation and did not attribute them with educational and inspirational values [26].

A network of green spaces (for example, parks) and blue spaces (for example, wetlands), productive natural landscapes such as allotment/domestic gardens, or a small-scale

ecological solution for stormwater management can all be considered as components of green infrastructure [35]. IGSs play a crucial role in managing stormwater runoff in urban areas [5]. They can absorb and retain rainfall, reducing the strain on drainage systems and helping to prevent flooding and water pollution. By allowing rainwater to infiltrate into the ground, these spaces contribute to groundwater recharge and help maintain water quality. IGSs, with their multiple benefits, contribute to creating healthier, more sustainable, and livable cities. They offer a range of positive impacts, including ecological, social, and psychological benefits, while contributing to the overall well-being of urban communities. Therefore, informal green space has many functions, so it is very worthy of the government's accumulation and investment in academic research.

2.3.2. Negative Impacts of "Informal Green Space"

While IGSs have numerous positive impacts, it is important to acknowledge that they can also have certain negative effects. The following are some of the potential negative impacts associated with IGSs: maintenance and management challenges, unequal distribution, safety concerns, environmental impacts, conflicts and disputes, and inadequate infrastructure and amenities.

IGSs often lack formal management structures and funding, which can lead to issues related to maintenance and upkeep [18]. Without proper management, these spaces may become overgrown, unkempt, or susceptible to invasive species. Neglected IGSs can create safety concerns, harbor pests, and become eyesores within the community. A study's results suggest that different maintenance regimes for IGSs may improve their contribution to urban conservation; therefore, it proposes adapting management to the local context [8].

IGSs may sometimes be associated with safety issues, especially if they are poorly lit, isolated, or lack surveillance. A study revealed that, while IGSs offered different ecosystem services, not all IGSs were accessible to children due to safety concerns, maintenance conditions, and parental restrictions [18]. These areas can become gathering places for illicit activities or vandalism, raising concerns about personal safety and community security. The perception of a lack of safety can deter people from using or enjoying these spaces. The results showed most respondents (>70%) remembered using informal urban green spaces in the past and preferred them over other green spaces because they were easily accessible; meanwhile, most (>70%) recalled experiencing no problems (e.g., danger of injury) when using IGSs, a contrast to recently increasing parental concern for children's safety [23]. Therefore, such factors may limit present informal urban green space use and prevent it from fulfilling the important role it played for previous generations' recreation [23].

IGSs, especially community gardens and allotments, may occasionally become sites of conflict or disputes among different stakeholders. Disagreements may arise over issues such as land tenure, resource allocation, or conflicting visions for the use of space. For example, in developing China, residents in many emerging urban communities of China have been appropriating and reclaiming public open spaces intentionally as a leisure opportunity and transforming their entertainment functions into vegetable plots, which has caused a series of conflicts and disputes [36]. Resolving these conflicts can be challenging and may require effective community engagement and mediation. Nevertheless, resolving the conflict between habitat service and cultural service through considering the temporary benefits of ecological succession and enhancing the public's accessibility and awareness of IGSs [37].

The parks and green squares are most frequently equipped with paths for night walks, playgrounds for children, outdoor gyms, flowerbeds, toilets, chess tables, bicycle paths, sculptures and monuments, and sports fields; in additionally, when it comes to recreational sites, playgrounds for children represent the most popular amenities, and followed by paths

for night walks [38]. IGSs may lack essential infrastructure and amenities that are commonly found in formal parks. This can include a lack of seating, garbage bins, lighting, or public restrooms. Insufficient infrastructure and amenities can limit the usability and accessibility of these spaces, particularly for individuals with disabilities or the elderly. Therefore, it is essential to address these negative impacts through effective management, community engagement, and equitable distribution of resources to ensure that IGSs continue to provide benefits while minimizing any adverse effects.

2.4. Public Opinion Survey

A public opinion survey, also known as an opinion poll or survey, is a research method used to measure and gather information about the attitudes, beliefs, and preferences of a particular population or group of individuals. These surveys aim to provide insights into public opinion on various topics, including politics, social issues, consumer behavior, and more. The questionnaire was developed based on a synthesis of the international literature on IGSs, particularly focusing on ecosystem services, public safety, and urban planning concerns as identified by Rupprecht et al. [8], Luo & Patuano [5], and Sikorska et al. [16].

Public opinion surveys can be conducted through various means, including telephone interviews, face-to-face interviews, online questionnaires, and mail-in surveys. Careful sample selection is essential to ensure the accuracy and representativeness of survey results. Public opinion surveys play a significant role in shaping public discourse and decision-making processes. They provide valuable insights into the opinions and preferences of the general population, allowing policy-makers, businesses, and organizations to gauge public sentiment and adjust their strategies accordingly. Overall, public opinion surveys serve as a valuable tool for understanding the thoughts and attitudes of the general public. They provide a quantitative measure of public opinion, which can be used to inform decision-making processes in politics, marketing, policy development, and more. However, it is crucial to interpret survey results critically and consider the limitations and potential biases inherent in the survey methodology.

Therefore, this study endeavors to elucidate the public's emphasis on the positive and negative perceptions of "informal green space" in Wenshan District, Taipei City. Firstly, the study conducted an analysis of the literature to identify eight positive impact items and six negative impact items of "informal green space". Subsequently, the degree of the public opinion survey of the positive and negative impacts of "informal green space" was obtained via a questionnaire. Finally, the research findings will be presented to the government as a reference for improving and managing informal green space.

The questionnaire was distributed through a random intercept approach, conducted in various public settings adjacent to identified IGSs (e.g., street verges, idle lots, and small parks). While the sampling was not stratified by demographic characteristics, we aimed for heterogeneity by varying the time of day and survey locations to reach respondents of diverse age, gender, and employment background. However, the survey did not deliberately target specific vulnerable subgroups, such as the elderly or persons with disabilities, and we acknowledge this as a methodological limitation. Given the importance of inclusive green space planning, we recommend that future research adopt stratified or purposive sampling techniques to ensure adequate representation of these groups and explore how their IGS perceptions may differ from the general population.

A pilot test involving 10 residents from the Wenshan District was conducted to refine item clarity, wording, and response interpretation. Based on pilot feedback, minor adjustments were made to the phrasing of several items to enhance readability and eliminate ambiguity. The final questionnaire consisted of 14 items: eight addressing perceived positive impacts and six focusing on perceived negative impacts of IGSs. Internal consis-

tency reliability was assessed using Cronbach's alpha, which yielded values of 0.82 for the positive impact scale and 0.79 for the negative impact scale, indicating acceptable to good reliability. This validation process supports the robustness of the survey as a tool for gauging residents' perceptions.

The survey was designed to minimize potential privacy concerns among respondents by avoiding the collection of personally sensitive information, including detailed socioeconomic status (SES) variables such as income, occupation, or household registration. Instead, the questionnaire focused on general perceptions, emotional responses, and usage behavior related to informal green spaces (IGSs), which are less likely to be influenced by SES in small-area studies. Furthermore, given the spatially constrained study area and the aim of capturing hyperlocal perceptions, a purposive sample of 52 valid responses was obtained from individuals with direct experience of IGSs in the neighborhood. Although the sample size is modest, it was sufficient to capture diverse narratives and usage patterns during the study period. Additional sampling was not pursued, as time-sensitive environmental and social conditions had changed since the initial fieldwork, making new data potentially non-comparable.

While the study collected 52 valid responses from residents in the Wenshan District, it is important to note that the relatively small sample size limits the statistical generalizability of the findings to the broader population of Taipei. Nevertheless, the results provide valuable exploratory insights into public perceptions of IGSs, especially in a high-density urban context where such spaces remain underexamined. Future studies with larger and more representative samples are encouraged to validate and expand upon these preliminary observations. To protect respondent anonymity and adhere to ethical standards in public intercept surveys, the questionnaire did not collect sensitive personal data such as age, household location, or precise residential distance from the surveyed IGSs. While this approach encouraged open participation and reduced privacy concerns, it also limited the ability to perform correlation or subgroup analyses between sociodemographic traits and IGSs' perception patterns.

3. Results

Through the analysis of previous domestic and foreign literature and relevant policy content, this study sorts out the following positive and negative impacts that IGSs may have on the environment, which are the following eight positive impacts: increasing or maintaining rich greening, increasing biological species richness, providing animal and plant habitats, purifying air quality, promoting residents' physical and mental health, providing recreational use, planting edible plants and activating urban space utilization; and six negative impacts: destroying environmental quality, affecting city appearance, producing garbage, and dumping waste space, breeding grounds for mosquito vectors, increased crime rates, and concerns about the safety of children.

The design of the self-administered questionnaire in this study adopts the Likert scale type, and the respondents answer the questions according to their subjective consciousness. The impact of the informal green space on the overall environment is divided into five points. The higher the score the higher the degree of influence; five means the highest degree of influence, and one means the least degree of influence. Aiming at the results of the questionnaires filled with personal experiences of the people, this study uses the mean, median, mode, standard deviation, and coefficient of variation to examine the degree of impact of different impact items on IGSs in the people's subjective consciousness (Tables 1 and 2).

Table 1. The degree of positive impact of IGSs by ranking order.

Positive Impact Item	Average	Standard Error	Median	Mode	Standard Deviation	Coefficient of Variation	Coefficient of Kurtosis	Coefficient of Skewness	Ranking
Increase or maintain rich greenery	4.087	0.165	4.000	4.000	0.793	0.628	−0.781	−0.762	1
For recreational use	3.957	0.247	4.000	5.000	1.186	1.407	0.191	−0.983	2
Promote the physical and mental health of residents	3.913	0.208	4.000	3.000	0.996	0.992	−1.502	−0.115	3
Provide habitat for flora and fauna	3.826	0.224	4.000	4.000	1.072	1.15	0.652	−0.834	4
Increase biological richness	3.652	0.205	4.000	4.000	0.982	0.964	1.372	−1.098	5
Clean air quality	3.696	0.183	4.000	3.000	0.876	0.767	−0.426	−0.219	6
Revitalize urban space utilization	3.522	0.207	3.000	3.000	0.994	0.988	−0.919	−0.066	7
Growing edible plants	3.087	0.273	3.000	2.000	1.311	1.719	−1.298	0.091	8

Table 2. The degree of negative impact of IGSs by ranking order.

Negative Impact Item	Average	Standard Error	Median	Mode	Standard Deviation	Coefficient of Variation	Coefficient of Kurtosis	Coefficient of Skewness	Ranking
Create waste storage space	4.000	0.235	4.000	5.000	1.128	1.273	0.673	−1.04	1
Breeding grounds for mosquito vectors	3.913	0.198	4.000	4.000	0.949	0.901	−0.512	−0.513	2
Safety concerns for children	3.87	0.17	4.000	4.000	0.815	0.664	−0.231	−0.297	3
Increased crime rate	3.261	0.22	3.000	4.000	1.054	1.111	−0.562	−0.032	4
Damage to the quality of the environment	3.174	0.232	3.000	2.000	1.114	1.241	−1.07	0.491	5
Affect the city's appearance	3.000	0.218	3.000	3.000	1.044	1.091	−0.445	0.262	6

The method of distributing questionnaires in this research is mainly based on the actual on-site distribution, and random distribution of questionnaires was adopted in the selection of distribution objects, and a total of 52 questionnaires were recovered (including 32 paper questionnaires and 20 online questionnaires). Although mean values were primarily used to rank the perceived importance of various IGS factors, skewness and kurtosis coefficients were analyzed to ensure the statistical appropriateness of this approach. A skewness value close to zero indicates a symmetrical distribution of responses, suggesting that the mean is a stable and unbiased measure of central tendency. Similarly, kurtosis values near zero suggest a mesokurtic distribution, implying that the responses do not exhibit extreme outliers or heavy tails. These indicators jointly validate the reliability of using mean scores for ranking, as they confirm that participant responses were normally distributed and not overly skewed or peaked.

3.1. The Degree of Positive Impact of IGSs

According to the analysis of respondents' positive impact on informal green space, from the perspective of kurtosis coefficient and skewness coefficient, the kurtosis coefficient of the questionnaire survey results is between −1.298 and 1.372, and the skewness

coefficient is between −1.098 Between and 0.091, it can be seen that the questionnaire result data presents a normal distribution. Regarding the distribution of the ratings given by the respondents, this study mainly uses the mean test to compare the arithmetic mean of the ratings of each item. According to the results of the questionnaire, most residents believe that IGSs can bring the following: 1. increase or maintain rich greenery, 2. provide recreational use, and 3. promote residents' physical and mental health and other positive effects. It can be seen that for the residents, they generally agree that informal green space can bring a positive impact of rich greening to the environment. Secondly, for the two effects of providing recreational use and promoting residents' physical and mental health, it means that residents agree with the entertainment provided by informal green space and can bring positive benefits to their physical and mental health. Among the assessed functions, planting edible crops received the lowest ratings, suggesting it holds less relevance for most residents. Obviously, for residents, whether the informal green space can be planted with edible plants is of little importance or influence.

3.2. The Degree of Negative Impact of IGSs

This study analyzes the degree of negative impact of respondents on informal green space and first judges whether the collected data is normally distributed. From the results, the kurtosis coefficient is between −0.562 and 0.673, and the skewness coefficient is between −0.562 and 0.673. Between −1.040 and 0.491, it means that the questionnaire results present a normal distribution. Secondly, this study uses the average test of the questionnaire results to compare the arithmetic mean of the scores of each item. According to the results of the questionnaire, the residents think that the informal green space has three negative impacts on the environment: 1. it becomes a space for dumping garbage, 2. it is a breeding ground for mosquitoes and vectors, 3. it has doubts about the safety of children, etc. These three negative impacts were rated as highly important by respondents. On the other hand, the two effects of affecting city appearance and destroying environmental quality are less important. In other words, the safety and sanitation management of informal green space is more important to residents.

3.3. Comprehensive Analysis

In order to strengthen people's willingness to use informal green space, according to the results of this study, the advantages of "informal green space" that the government must strengthen are as follows: increase or maintaining rich greenery, for recreational use, and promoting the physical and mental health of residents. First of all, the government can promote the informal green space to increase the amount of greening through policies to meet the expectations of the public. Through government subsidies, the community can plant, manage, and maintain plants. In addition, the leisure and entertainment functions of IGSs accessible to the community can be discussed through public participation, and the leisure functions of IGSs can be strengthened with government funding or corporate sponsorship. Finally, as the functions of IGSs are improved, the physical and mental health of the people living around them can be improved.

On the other hand, according to the results of this study, people think that the most important negative impacts of "IGSs" are as follows: creating waste storage space, breeding grounds for mosquito vectors, and safety concerns for children. Therefore, through public participation management mechanisms (such as community adoption), the problems of clutter and mosquito breeding in IGSs can be reduced. Moreover, through security equipment and a public watch and help mechanism, the safety of children using IGSs can be ensured. Only by trying to improve the positive benefits of IGSs and reduce the negative

dangers and risks can people be willing to use IGSs, and IGSs can complement urban parks and green spaces.

4. Discussion

The findings of this study highlight both the recognized benefits and prevailing concerns regarding IGSs in dense urban environments such as Taipei. The residents' evaluation reveals the following duality: while IGSs are broadly appreciated for their environmental and recreational functions, their unmanaged nature and ambiguous governance give rise to safety and sanitation concerns. This dual perception aligns with patterns reported in prior studies conducted in Japan [1,2], Europe [16,26], and Africa [18].

4.1. Public Valuation of Ecosystem Services and Everyday Functions

Among the eight positive impacts assessed, the highest-rated aspects—enhancing urban greening, enabling recreational use, and supporting physical and mental health—align closely with cultural and regulating ecosystem services identified in the literature [5,8,27]. These findings support the view that residents regard IGSs as not merely supplementary, but as integral, lived components of the urban environment that contribute to everyday urban life. Such perceptions provide valuable support for integrating IGSs into broader green infrastructure strategies [14,35].

However, lower scores for impacts such as "planting edible plants" suggest a more limited resident awareness or engagement with the productive functions of IGSs, such as urban agriculture. This may reflect both cultural attitudes and the limited institutional support for community gardening initiatives in Taipei, as observed similarly in China [36]. Strengthening policy and educational efforts to promote multifunctional use of IGSs may enhance both their perception and ecological utility.

Although the sample size in this study is modest, the findings serve an important exploratory function by illuminating patterns in residents' valuations and concerns regarding IGSs. These insights can inform hypothesis generation and guide the design of broader, citywide or cross-city comparative studies. Moreover, the survey results complement the qualitative and literature-based components of the research, enhancing its overall relevance for adaptive urban land governance discussions. The use of mean values for ranking is supported by the skewness and kurtosis statistics reported in Section 3. Most items fell within acceptable thresholds ($|\text{skewness}| < 0.5$, $|\text{kurtosis}| < 1$), indicating consistent and normally distributed responses across participants. This statistical robustness strengthens the validity of the comparative ranking of perception factors.

4.2. Safety and Management as Constraints to Full Utilization

Residents' concerns about IGSs—particularly waste dumping, mosquito breeding, and child safety—mirror the most common barriers to informal space usage reported internationally [6,18]. While more than 70% of respondents reported having used IGSs previously, their willingness to continue such usage appears conditional on perceived management quality and safety conditions, consistent with observations in Rupprecht et al. [23].

However, to fully appreciate these concerns, it is crucial to consider the inherent unpredictability and affective dimensions of IGSs. As Simandan [39] argues, experiences of fear or anxiety in urban environments often stem from the potential for "negative surprise"—such as unexpectedly encountering wildlife (e.g., snakes, raccoons, or coyotes) or illicit activity. These moments of unexpected confrontation evoke deeper feelings of spatial discomfort or even territorial alienation. Thus, residents' fears are not just about sanitation or maintenance per se, but also about the psychological unease produced by spatial ambiguity and uncontrolled nature within the city. This interpretation helps explain

why the negative perception of IGSs does not simply correlate with objective disorder, but rather emerges from a complex interplay of surprise, bodily response, and socio-cultural expectations of what urban nature should feel like.

Notably, concerns related to esthetics or urban design—such as visual disorder—received lower levels of negative response. This suggests that for Taipei residents, IGSs are not rejected on grounds of visual informality per se, but rather due to perceived disorder or neglect. This distinction is important for land governance approaches: interventions should prioritize sanitation and community safety mechanisms over visual beautification alone.

4.3. Implications for Urban Land Governance

The results confirm that IGSs in Taipei occupy a gray zone in land governance—neither fully public nor private, formally designated nor entirely abandoned. This governance ambiguity is a central challenge in recognizing IGSs as legitimate urban land uses [3,4,37]. As Włodarczyk-Marciniak et al. [26] suggest, minor design interventions and clearer maintenance regimes can significantly improve public perception without compromising the spontaneous and flexible nature of IGSs.

Furthermore, citizen participation emerges as a key solution. The study supports earlier findings that community adoption models, such as co-maintenance or stewardship programs, can simultaneously reduce the negative impacts (e.g., waste and vector risk) and strengthen residents' place attachment and informal land use legitimacy [17,22].

This echoes earlier findings by Sun et al. [40], who examined eco-communities in Taiwan and emphasized the importance of multilevel governance involving government support, intermediary partnerships, and community engagement. While situated in a different spatial context, their tripartite framework of institutional coordination offers valuable insights for addressing the governance ambiguity of informal green spaces in dense urban settings.

Similarly to the study by Kim et al. [1], this study finds that safety, accessibility, and ecological value are central to residents' perceptions of IGSs. However, our findings diverge in that Taipei residents showed stronger awareness of governance limitations and expressed more interest in community co-management. This may reflect Taipei's denser urban fabric and more active civil society participation.

One critical dimension of governance ambiguity—land ownership or tenure status—was not directly addressed in the present survey. Residents' perceptions of whether IGS parcels are public, private, or "no-man's-land" may significantly shape their attitudes toward usage rights, co-management potential, and policy interventions. However, since the current questionnaire was finalized before this issue was identified, no specific questions on tenure awareness or assumptions were included. Future studies would benefit from incorporating such items to better understand how legal uncertainty influences community interaction with IGSs.

Based on survey responses and field observations by this study, several practical strategies may help address the following negative perceptions identified:

- "Environmental degradation (e.g., trash accumulation, pollution) can be mitigated through community-led cleanup events and municipal micro-maintenance funding, especially in areas not covered by formal park services".
- "Visual disorder, often stemming from overgrowth or disorganized vegetation, could be addressed by light-touch landscape management—such as regular trimming or selective planting—without compromising the informal or spontaneous character of the site".

- "To alleviate safety concerns, especially in sites perceived as hidden or dark, simple measures like solar lighting, clear sightlines, and occasional patrol signage have been recommended by users".
- "Perceived vacancy or underutilization could be counteracted by community activation, such as installing temporary seating, play structures, or hosting pop-up events that increase visibility and frequency of positive use".

These targeted, low-cost interventions reflect a form of "minimum viable governance" suitable for informal, fragmented green parcels and could serve as a bridge between fully planned spaces and neglected urban voids.

4.4. Towards a Hybrid Green Space Framework

This study reinforces the call for a hybrid urban green space framework—one that integrates formal and informal spaces to maximize spatial coverage and functional diversity [15,25]. Rather than relying solely on planned parks, municipal governments can adopt inclusive planning frameworks that valorize existing IGSs, support community engagement, and address site-specific risks. In compact cities like Taipei, such approaches may be particularly effective for ensuring green space equity and resilience under land scarcity conditions. These findings resonate with Simandan's notion of urban wisdom as a balancing act between planning formality and ecological openness [29]. In this light, IGSs represent hybrid ecologies [30] that challenge rigid classifications and offer fertile ground for inclusive urban imaginaries [31].

The findings suggest that IGSs complement formal green infrastructure rather than replace it. Unlike planned parks, which offer standardized recreational amenities, IGSs serve hyperlocal and adaptive functions that are particularly valuable in land-scarce contexts. A hybrid approach that integrates the spontaneity and community-driven aspects of IGSs with the stability and predictability of formal green spaces could enhance green equity and resilience.

At the policy level, this implies updating existing land use classifications and green space inventories to acknowledge and incorporate IGS typologies, and to fund micro-scale, community-led interventions. Planning regulations should further recognize IGSs as provisional but functional components of urban green infrastructure, capable of adapting to shifting demographic and spatial dynamics. In addition, a notable methodological limitation is the absence of sociodemographic and spatial proximity data, which precluded correlation analyses between variables such as age, IGS familiarity, or residential distance. While our descriptive statistics yielded meaningful patterns, future studies should consider integrating optional demographic and locational questions—with appropriate consent—to enable richer inferential analyses and segmentation of user perceptions. This would be especially valuable for tailoring IGS governance strategies to different resident groups.

5. Conclusions

In the Taipei Metropolitan Area, the population density after urban development is much higher than expected, and the current situation of limited urban green space is not likely to increase significantly. Therefore, IGSs can provide people with space for leisure and recreation. Urban planners have always been tasked with the challenge of providing more green spaces for city residents within limited urban space and budgets. In recent years, several studies have suggested that the shortage of urban parks and green spaces can be addressed by utilizing IGSs.

According to the results of this study, the advantages of "IGSs" that the government must strengthen are as follows: increasing or maintaining rich greenery, for recreational use, promoting physical and mental health of residents. Therefore, the government can promote

the IGSs to increase the amount of greening through policies to meet the expectations of the public. In addition, the leisure and entertainment functions of IGSs accessible to the community can be discussed through public participation, and the leisure functions of IGSs can be strengthened with government funding or corporate sponsorship.

In addition, according to the results of this study, people think that the most important negative impacts of IGSs are as follows: creating waste storage space, breeding grounds for mosquito vectors, and safety concerns for children. Therefore, through public participation management mechanisms (such as community adoption), the problems of clutter and mosquito breeding in IGSs can be reduced. Moreover, through security equipment and a public watch and help mechanism, the safety of children using IGSs can be ensured.

In summary, this study lists the positive and negative influencing factors of informal green spaces with reference to the relevant literature and obtains the people's most real thoughts on IGSs through questionnaires. The findings indicate that all evaluated factors received mean scores above 3.0, suggesting that residents generally attribute at least moderate importance to both positive and negative aspects of IGSs. In particular, people believe that the most important positive impact of IGSs is to increase the amount of greening in cities and communities, and they are most worried that IGSs will become a storage space for garbage and waste. However, relevant research results have also concluded that proper management of IGSs or increased usage can help reduce the amount of garbage and crime in these spaces. Therefore, the management and maintenance of informal green spaces are very important to improve urban landscape, safety, and function.

This study reveals that while residents value IGSs for their ecological and recreational functions, concerns over safety and sanitation pose persistent challenges to their full integration into urban life. Rather than viewing IGSs as marginal or temporary, our findings underscore their potential as essential components of urban green infrastructure—particularly in space-constrained contexts. These dual perceptions reflect a broader socio-ecological tension that urban policymakers must address by designing governance frameworks that balance community empowerment with safety and maintenance protocols.

Theoretically, this study contributes to the evolving discourse on informal urbanism by empirically demonstrating how residents' ecological, recreational, and safety perceptions shape the socio-political legitimacy of IGSs. It supports the view that informal spaces are not merely residual but function as contingent commons—informally governed areas that demand adaptive policy responses.

These findings are particularly relevant for other densely populated Asian cities facing land scarcity and fragmented green networks, offering a transferable model for integrating resident perceptions into IGS governance and participatory planning frameworks.

In sum, IGSs in Taipei are valued by residents not only for their environmental functions but also for their contributions to well-being and social cohesion. At the same time, perceived risks such as safety and poor maintenance hinder broader usage. These results suggest that IGSs should not be regarded as leftover land but as latent ecological assets requiring tailored governance. Theoretically, this study expands the discourse on informal urbanism by framing IGSs as contingent commons, where legitimacy arises through community perceptions and co-management. For other dense Asian cities grappling with similar spatial and governance constraints, our findings provide a foundation for developing hybrid green space policies that are inclusive, flexible, and grounded in local values.

In addition to enhancing residents' recognition of ecological and social benefits, it is equally important to respond to negative perceptions through adaptive, site-specific interventions. Based on both survey feedback and on-site observations, this study recommends municipal support for light-touch maintenance, participatory design, and stewardship

incentives as feasible strategies to improve user experience without requiring large-scale redevelopment or rezoning.

This study has two primary limitations. First, the relatively small sample size (n = 52) restricts the statistical generalizability of the findings. However, given the localized nature of IGSs and the exploratory focus of this research, the sample was sufficient to identify key perceptual trends and qualitative insights within the study area. Second, the study did not collect detailed SES data to avoid raising privacy concerns, especially in an urban setting where distrust or suspicion toward surveys may reduce response quality. While this limits the ability to analyze perception differences by income or class, future studies can build upon our framework with stratified sampling and expanded demographic profiling to address equity-related issues more explicitly.

Due to the exploratory nature and limited sample size of this study, caution should be exercised when generalizing the findings. Future studies should consider stratified sampling and subgroup targeting, particularly to understand the needs and experiences of vulnerable populations such as older adults and persons with mobility constraints. In addition, future studies should explore residents' perceptions of land ownership and tenure in relation to IGSs. Understanding whether users believe IGSs are publicly owned, privately abandoned, or ambiguously governed can offer deeper insight into the socio-political legitimacy of these spaces and guide more effective community-based governance models. Future survey designs might benefit from using more explicit phrasing or visual prompts to ensure semantic clarity between environmental and esthetic perceptions of IGSs.

Moreover, this study is based on a relatively small sample size (n = 52), which limits the statistical generalizability of the findings. Additionally, detailed socioeconomic status (SES) indicators—such as income level, employment type, and housing tenure—were not collected. As a result, potential associations between SES and residents' perceptions of informal green spaces could not be thoroughly examined. Future research should incorporate a broader range of SES variables and expand the respondent pool to better assess equity-related dimensions of IGSs.

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Institutional Review Board Statement: According to the 'Scope of Human Research Exempt from Review by an Institutional Review Board' issued by the Taiwan Ministry of Education (5 July 2012), this study qualifies for exemption. The research involved anonymous, non-interactive, and non-interventional public questionnaire surveys conducted in open spaces, with no collection of identifiable personal data. Therefore, ethical approval was not required, and no formal exemption certificate could be obtained post hoc due to institutional policy allowing only prior applications for exemption.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions related to human subject participation.

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References

1. Kim, M.; Rupprecht, C.D.D.; Furuya, K. Residents' Perception of Informal Green Space—A Case Study of Ichikawa City, Japan. *Land* **2018**, *7*, 102. [CrossRef]
2. Rupprecht, C.D.D. Informal Urban Green Space: Residents' Perception, Use, and Management Preferences across Four Major Japanese Shrinking Cities. *Land* **2017**, *6*, 59. [CrossRef]
3. Rupprecht, C.D.D.; Byrne, J.A. Informal urban greenspace: A typology and trilingual systematic review of its role for urban residents and trends in the literature. *Urban For. Urban Green.* **2014**, *13*, 597–611. [CrossRef]
4. Rupprecht, C.D.D.; Byrne, J.A. Informal Urban Green-Space: Comparison of Quantity and Characteristics in Brisbane, Australia and Sapporo, Japan. *PLoS ONE* **2014**, *9*, e99784. [CrossRef]
5. Luo, S.; Patuano, A. Multiple ecosystem services of informal green spaces: A literature review. *Urban For. Urban Green.* **2023**, *81*, 127849. [CrossRef]
6. Długoński, A.; Dushkova, D. The Hidden Potential of Informal Urban Greenspace: An Example of Two Former Landfills in Post-Socialist Cities (Central Poland). *Sustainability* **2021**, *13*, 3691. [CrossRef]
7. Rupprecht, C.D.D.; Byrne, J.A.; Ueda, H.; Lo, A.Y. 'It's real, not fake like a park': Residents' perception and use of informal urban green-space in Brisbane, Australia and Sapporo, Japan. *Landsc. Urban Plan.* **2015**, *143*, 205–218. [CrossRef]
8. Rupprecht, C.D.D.; Byrne, J.A.; Garden, J.G.; Hero, J.-M. Informal urban green space: A trilingual systematic review of its role for biodiversity and trends in the literature. *Urban For. Urban Green.* **2015**, *14*, 883–908. [CrossRef]
9. Kabisch, N. Ecosystem service implementation and governance challenges in urban green space planning—The case of Berlin, Germany. *Land Use Policy* **2015**, *42*, 557–567. [CrossRef]
10. Sun, C.Y.; Lin, H.T.; Ou, W.S. The Relationship Between Urban Greening and Thermal Environment. In Proceedings of the 2007 Urban Remote Sensing Joint Event, Paris, France, 11–13 April 2007; pp. 1–6.
11. Sun, C.Y. The Thermal Influence of Green Roofs on Air Temperature in Taipei City. *Appl. Mech. Mater.* **2011**, *44–47*, 1933–1937. [CrossRef]
12. Sun, C.-Y.; Brazel, A.J.; Chow, W.T.L.; Hedquist, B.C.; Prashad, L. Desert heat island study in winter by mobile transect and remote sensing techniques. *Theor. Appl. Climatol.* **2009**, *98*, 323–335. [CrossRef]
13. Sun, C.Y.; Lin, Y.J.; Sung, W.P.; Ou, W.S.; Lu, K.M. Green Roof as a Green Material of Building in Mitigating Heat Island Effect in Taipei City. *Appl. Mech. Mater.* **2012**, *193–194*, 368–371. [CrossRef]
14. Archiciński, P.; Przybysz, A.; Sikorska, D.; Wińska-Krysiak, M.; Da Silva, A.R.; Sikorski, P. Conservation Management Practices for Biodiversity Preservation in Urban Informal Green Spaces: Lessons from Central European City. *Land* **2024**, *13*, 764. [CrossRef]
15. Kim, M.; Rupprecht, C.D.D.; Furuya, K. Typology and Perception of Informal Green Space in Urban Interstices: A case study of Ichikawa City, Japan. *Int. Rev. Spat. Plan. Sustain. Dev.* **2020**, *8*, 4–20. [CrossRef] [PubMed]
16. Sikorska, D.; Łaszkiewicz, E.; Krauze, K.; Sikorski, P. The role of informal green spaces in reducing inequalities in urban green space availability to children and seniors. *Environ. Sci. Policy* **2020**, *108*, 144–154. [CrossRef]
17. Pietrzyk-Kaszyńska, A.; Czepkiewicz, M.; Kronenberg, J. Eliciting non-monetary values of formal and informal urban green spaces using public participation GIS. *Landsc. Urban Plan.* **2017**, *160*, 85–95. [CrossRef]
18. Pedrosa, E.L.; Okyere, S.A.; Frimpong, L.K.; Diko, S.K.; Commodore, T.S.; Kita, M. Planning for Informal Urban Green Spaces in African Cities: Children's Perception and Use in Peri-Urban Areas of Luanda, Angola. *Urban Sci.* **2021**, *5*, 50. [CrossRef]
19. Afrad, A.; Kawazoe, Y. Can interaction with informal urban green space reduce depression levels? An analysis of potted street gardens in Tangier, Morocco. *Public Health* **2020**, *186*, 83–86. [CrossRef]
20. Douglas, O.; Lennon, M.; Scott, M. Green space benefits for health and well-being: A life-course approach for urban planning, design and management. *Cities* **2017**, *66*, 53–62. [CrossRef]
21. Hunter, R.F.; Cleland, C.; Cleary, A.; Droomers, M.; Wheeler, B.W.; Sinnett, D.; Nieuwenhuijsen, M.J.; Braubach, M. Environmental, health, wellbeing, social and equity effects of urban green space interventions: A meta-narrative evidence synthesis. *Environ. Int.* **2019**, *130*, 104923. [CrossRef]
22. Mahmoudi Farahani, L.; Maller, C. Investigating the benefits of 'leftover' places: Residents' use and perceptions of an informal greenspace in Melbourne. *Urban For. Urban Green.* **2019**, *41*, 292–302. [CrossRef]
23. Rupprecht, C.D.D.; Byrne, J.A.; Lo, A.Y. Memories of vacant lots: How and why residents used informal urban green space as children and teenagers in Brisbane, Australia, and Sapporo, Japan. *Child. Geogr.* **2016**, *14*, 340–355. [CrossRef]
24. Wood, L.; Hooper, P.; Foster, S.; Bull, F. Public green spaces and positive mental health—Investigating the relationship between access, quantity and types of parks and mental wellbeing. *Health Place* **2017**, *48*, 63–71. [CrossRef]
25. Vereecken, N.J.; Weekers, T.; Marshall, L.; D'Haeseleer, J.; Cuypers, M.; Pauly, A.; Pasau, B.; Leclercq, N.; Tshibungu, A.; Molenberg, J.-M.; et al. Five years of citizen science and standardised field surveys in an informal urban green space reveal a threatened Eden for wild bees in Brussels, Belgium. *Insect Conserv. Divers.* **2021**, *14*, 868–876. [CrossRef]

26. Włodarczyk-Marciniak, R.; Sikorska, D.; Krauze, K. Residents' awareness of the role of informal green spaces in a post-industrial city, with a focus on regulating services and urban adaptation potential. *Sustain. Cities Soc.* **2020**, *59*, 102236. [CrossRef] [PubMed]
27. Sikorski, P.; Gawryszewska, B.; Sikorska, D.; Chormański, J.; Schwerk, A.; Jojczyk, A.; Ciężkowski, W.; Archiciński, P.; Łepkowski, M.; Dymitryszyn, I.; et al. The value of doing nothing—How informal green spaces can provide comparable ecosystem services to cultivated urban parks. *Ecosyst. Serv.* **2021**, *50*, 101339. [CrossRef]
28. Manyani, A.; Shackleton, C.M.; Cocks, M.L. Attitudes and preferences towards elements of formal and informal public green spaces in two South African towns. *Landsc. Urban Plan.* **2021**, *214*, 104147. [CrossRef]
29. Simandan, D. The wise stance in human geography. *Trans. Inst. Br. Geogr.* **2011**, *36*, 188–192. [CrossRef]
30. Whatmore, S. Hybrid geographies: Rethinking the 'human'in human geography. In *Environment*; Routledge: London, UK, 2017; pp. 411–428.
31. Gandy, M. *Natura Urbana: Ecological Constellations in Urban Space*; MIT Press: Cambridge, MA, USA, 2022.
32. Feltynowski, M.; Kronenberg, J.; Bergier, T.; Kabisch, N.; Łaszkiewicz, E.; Strohbach, M.W. Challenges of urban green space management in the face of using inadequate data. *Urban For. Urban Green.* **2018**, *31*, 56–66. [CrossRef]
33. Coombes, E.; Jones, A.P.; Hillsdon, M. The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Soc. Sci. Med.* **2010**, *70*, 816–822. [CrossRef]
34. Peters, K.; Elands, B.; Buijs, A. Social interactions in urban parks: Stimulating social cohesion? *Urban For. Urban Green.* **2010**, *9*, 93–100. [CrossRef]
35. Adegun, O.B. Green infrastructure in relation to informal urban settlements. *J. Archit. Urban.* **2017**, *41*, 22–33. [CrossRef]
36. He, B.; Zhu, J. Constructing community gardens? Residents' attitude and behaviour towards edible landscapes in emerging urban communities of China. *Urban For. Urban Green.* **2018**, *34*, 154–165. [CrossRef]
37. Mathey, J.; Rößler, S.; Banse, J.; Lehmann, I.; Bräuer, A. Brownfields as an Element of Green Infrastructure for Implementing Ecosystem Services into Urban Areas. *J. Urban Plan. Dev.* **2015**, *141*, A4015001. [CrossRef]
38. Łaszkiewicz, E.; Czembrowski, P.; Kronenberg, J. Creating a Map of the Social Functions of Urban Green Spaces in a City with Poor Availability of Spatial Data: A Sociotope for Lodz. *Land* **2020**, *9*, 183. [CrossRef]
39. Simandan, D. Being surprised and surprising ourselves: A geography of personal and social change. *Prog. Hum. Geogr.* **2020**, *44*, 99–118. [CrossRef] [PubMed]
40. Sun, C.-Y.; Chen, Y.-A.; Zhang, X. Key Factors in the Success of Eco-Communities in Taiwan's Countryside: The Role of Government, Partner, and Community Group. *Sustainability* **2019**, *11*, 1208. [CrossRef]

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Navigating the Path to Smart and Sustainable Cities: Insights from South Korea's National Strategic Smart City Program

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Abstract: This study evaluates the progress of Korea's National Strategic Smart City Program (NSSCP), a flagship R&D initiative, in advancing sustainable and intelligent urban development on a global scale. Utilizing the United Nations' United for Smart Sustainable Cities (U4SSC) framework, which integrates both sustainability and smartness in city development, this research examines the program's alignment with global standards. The findings reveal that the NSSCP contributes to the attainment of the Sustainable Development Goals (SDGs) in areas such as health, energy, innovation, and sustainable communities. It also effectively addresses key dimensions of smart cities, including smart living, environmental stewardship, mobility, and economic vitality. Despite these achievements, this study identifies critical challenges, such as the absence of robust evaluation tools and an overemphasis on quantitative targets. This research is important in advancing the discourse on smart city development, offering insights into the efficacy of smart services and systems through the lens of the NSSCP's cloud-based open data hub model.

Keywords: National Strategic Smart City Program (NSSCP); United for Smart Sustainable Cities (U4SSC); Sustainable Development Goals (SDGs); South Korea; program evaluation

1. Introduction

1.1. Research Background

The global transition toward smart cities is accelerating, with many countries actively developing national strategies. Notably, G20 nations have announced formal smart city initiatives [1]. Since 2017, South Korea has launched numerous smart city projects, building on earlier efforts under the "Ubiquitous City (U-City)" framework. Among these, the National Strategic Smart City Program (NSSCP) stands out as the largest and most recent initiative led by the central government. Implemented over five years (2018–2022), the NSSCP was coordinated by the Ministry of Land, Infrastructure, and Transport (MOLIT) and the Ministry of Science and ICT (MSIT), with a total investment of approximately USD 101 million. At its core, the NSSCP aimed to establish a centralized data hub as the foundation for smart city development and to pilot cutting-edge technologies in two major urban areas: Daegu Metropolitan City (Gyeongsang Province) and Siheung City (Gyeonggi Province).

Smart cities have emerged as potential solutions to the challenges of urban sustainability. However, it remains unclear whether smart city initiatives effectively lead to environmental, economic, and social sustainability outcomes. This uncertainty stems from the lack of holistic evaluations assessing the actual sustainability impacts of smart

city projects [2]. Nevertheless, analyzing smart cities through the lens of sustainability is essential to ensure their long-term viability and to maintain a balance across environmental, social, and economic dimensions. In particular, this underscores the importance of integrating sustainability into smart city frameworks to address the complex challenges of urbanization effectively [3]. Trindade et al. [4] also emphasizes the need for forward-looking studies to examine the critical question of whether the smart city concept and its practices can truly contribute to urban sustainability.

Against this backdrop, the present study aims to assess whether the NSSCP, South Korea's flagship smart city initiative, is progressing in a sustainable direction. Although 13 notable smart city projects have been implemented in South Korea [5], none have been evaluated from a sustainability-oriented perspective.

1.2. Related Studies and Research Purpose

There are relatively few studies that comprehensively analyze the NSSCP. Lee and Park [6] provide a general overview of the outcomes from smart city pilot projects and suggest directions for the expansion of data-driven smart cities in South Korea. Yang et al. [7], who conducted a more detailed analysis, compared the NSSCP with smart city initiatives in other countries, focusing on service domains. They found that, while leading global cities typically provide six core services—smart grids, renewable energy, parking management, 3D city models, and citizen engagement platforms—South Korea emphasizes the deployment of advanced communication technologies and data analytics (e.g., electricity demand forecasting and fine dust monitoring), along with the development of emerging technologies such as autonomous driving. The NSSCP has concentrated on delivering services in transportation, living, and built infrastructure, thereby reinforcing South Korea's strengths in related core technologies.

However, the authors point out that South Korea's traditionally top-down approach to smart city development, led primarily by the central government, has resulted in limited initiative and adaptability among service providers. Lim and Kim [8] also examined the NSSCP using the Stage-Gate model, a conceptual and operational framework to guide new product development from idea to launch. Their study suggests that large-scale transformation programs like the NSSCP could benefit from adopting more market-oriented Stage-Gate models to improve the investment efficiency, enhance the research quality, and support successful demonstrations and commercialization.

While these studies offer valuable insights, their analyses of the NSSCP remain largely at the micro level. As previously noted, a more comprehensive evaluation of whether smart city initiatives contribute meaningfully to sustainable urban development is essential in informing effective smart city policies and implementation strategies. Moreover, given the global proliferation of smart city projects, understanding their successes and limitations is critical in shaping future improvements [9]. As Li et al. [10] emphasize, systematic evaluation plays a vital role in guiding and fostering the development of smart cities. Nevertheless, the current evaluation efforts remain in their early stages, often focusing on isolated aspects and relying on indicators with limited scalability. These evaluations also tend to lack alignment with widely accepted and interoperable smart city frameworks [10].

Against this backdrop, this study aims to address the following research question: How effective is South Korea's smart city promotion strategy in enhancing sustainability and smartness in urban areas? To answer this question, this study critically evaluates the outcomes of the NSSCP using the United for Smart Sustainable Cities (U4SSC) framework—a global initiative led by international organizations such as the International Telecommunication Union (ITU), the United Nations Economic Commission for Europe (UNECE), and UN-Habitat. Specifically, this study assesses the extent to which the NSSCP aligns with the

Key Performance Indicators (KPIs) established by U4SSC. This evaluation involves analyzing the goals, content, and anticipated outcomes of the NSSCP's 13 projects to determine their effectiveness in meeting U4SSC's KPIs.

To achieve this, this study follows the research process illustrated in Figure 1.

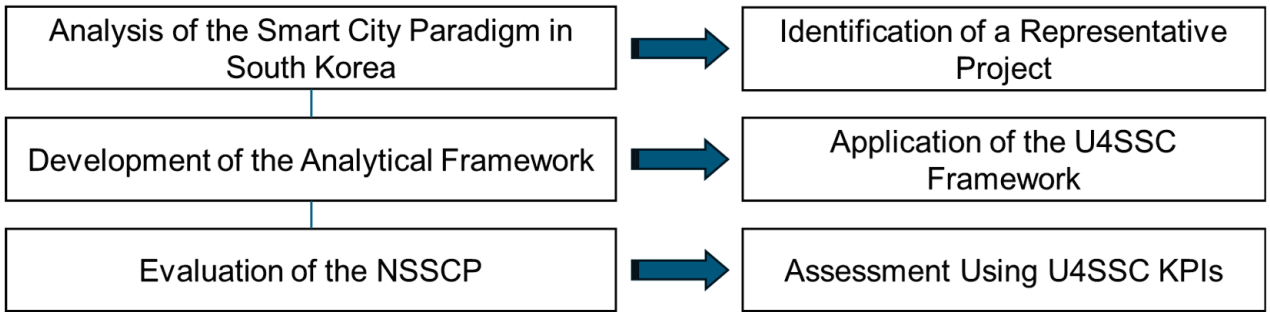

Figure 1. Research flowchart.

2. Materials and Methods

2.1. Research Target: National Strategic Smart City Program in South Korea

Korea's smart city development began in the early 2000s with the Ubiquitous City (U-City) project, focused on new towns like Hwaseong, Dongtan, and Songdo. Initiated by the public sector, the project was supported by the 2008 U-City Act, which aimed to streamline the construction and management of these cities. However, the concept of smart cities has since evolved, with the private sector now playing a pivotal role in ongoing innovation and technology integration. Smart city development has become a shared objective, essential for both new and existing urban areas [11].

Korea's smart city policy has progressed through several stages. The first stage, up to 2013, involved the U-City project, which integrated ICT with urban development. This phase included the U-Eco City R&D project, funded at USD 84.49 million, to develop basic services, technology, and platforms. The second stage (2014–2017) focused on enhancing infrastructure utilization through projects like the Smart City Information R&D project, which aimed to develop intelligent urban infrastructure. During this period, the Smart City Integrated Platform (SCIP) was introduced, providing cloud-based services for emergency and disaster management across municipalities. The third stage, from 2018 onwards, expanded the scope to include new concepts like testbeds, living labs, and fourth industrial revolution technologies. The government's "Korean New Deal" initiatives, including the 2020 Digital New Deal, emphasize data-driven urban management and innovation. This stage marks a shift toward a more inclusive and globally connected smart city ecosystem [11–13] (see Figure 2).

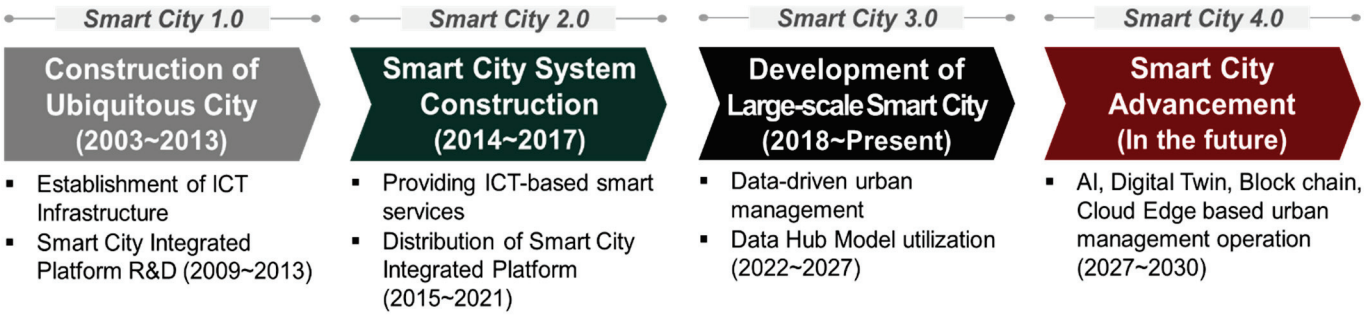

Figure 2. Korea's smart city development stages.

Korea defines a smart city as a platform leveraging fourth industrial revolution technologies to enhance quality of life, sustainability, and new industries. The government supports this through substantial investment and deregulation, with 78 local governments actively participating in smart city projects. The national smart city policy is guided by three visions: solving urban problems through advanced technology, developing inclusive cities, and fostering global collaboration. These are supported by four strategic goals and a five-year roadmap [12].

The National Strategic Smart City Program (NSSCP) was a major R&D initiative with a USD 101 million budget, running from 2018 to 2022. Funded by the government, local authorities, and the private sector, it involved 132 institutions and 1400 participants. The program aimed to develop data-driven smart cities that address urban challenges, improve quality of life, and promote sustainable economic growth. Key projects included developing a data hub model; implementing use cases in transportation, safety, and public administration; and conducting living lab demonstrations in the energy, environment, and welfare sectors. These efforts were expected to contribute significantly to Korea's digital transformation under the New Deal (see Table 1).

Table 1. Summary of the National Strategic Smart City Program.

Category	Project Title	Details	Keywords
1. Development of Smart City Model and Base Technology	A. Open Data Hub Architecture and Core Technology	• Design of cloud-based open data hub architecture model to collect, process, and store data with standard data models and interfaces	Data Hub
	B. Massive Real-Time IoT Infrastructure and Network Technology	• Development of intelligent IoT devices, infrastructure enhancement, network establishment, and control technology for massive IoT data (transportation, environment, energy, safety) processing in various communication environments	Massive IoT
	C. Digital Twin Smart City Service Virtualization Technology	• Using virtual platform technology development for rendering and real-time synchronization of data-hub-collected data in digitalized virtual space	Digital Twin
	D. Smart City Project Management, Evaluation Model, and Cooperation Program	• Developing a model to manage the smart city R&D project, as well as creating a system for the accumulation and spread of knowledge to implement the project successfully	R&D Management
2. Citizen-Centric Service Enhancement (Use Case Model)	A. Smart Mobility and Smart Parking Service Technology	• Providing personalized smart mobility services that aim to mitigate traffic congestion on roadways and enhance user convenience in public and private transportation	Mobility

Table 1. *Cont.*

Category	Project Title	Details	Keywords
2. Citizen-Centric Service Enhancement (Use Case Model)	B. Data-Sharing Safety Technology (Natural Disaster in Urban Areas and Emergency Rescue Technology)	• Development of disaster real-time collection, real-time prediction/analysis/sharing system, and rescue services	Safety (Disaster and Emergency Management)
	C. Data Hub Center and City Administration Technology	• Considering the status of Daegu Metropolitan City, the development and operation of the data hub center for use case services and citizen participation	Data Hub and Urban Administration
	D. Data-Based Smart City Use-Case Development for Solving Urban Problems with Citizen Participation	• Specific service solutions development and real-life verification through citizen participation using design thinking methodology for global competitiveness	Citizen Participation
3. Technology Innovation and Business Intelligence (Living Lab Model)	A. Crowdsourcing Urban Air Quality Measurement and Forecasting Technology	• 2D/3D analysis information mapping and forecasting technology based on crowdsourcing, development of analysis technology for pollution sources, and information provision system	Sustainable Environment
	B. Integrated Energy Management System (Xems) for Home/Building/ Factor/Public Facilities	• Development and demonstration of integrated operation technology to improve the energy efficiency of the city	Total Energy Management System
	C. Total Care System for the Elderly Living Alone and Mobility Assurance System for the Disabled	• Demonstration of living labs by developing and deploying a total care service platform for the elderly inside and outside the office	Social Health Care
	D. Open Data Hub Platform Based on the Living Lab Innovation Model	• Build and demonstrate a data hub platform based on open data hub architecture	Data Hub
	E. Smart City Business Model Based on Needs in Local Society	• Establishment of a smart city business model and support system for the industrial competitiveness of Siheung City	Business Creation and Citizen Participation

Source: Modified based on KAIA [14].

2.2. Theoretical Framework: United 4 Smart Sustainable Cities (U4SSC) Initiative

Smart cities have begun to play a central role in the sustainable development agenda of major economies, including the European Union [15]. The U4SSC initiative defines a smart sustainable city as "an innovative city that uses ICT and other means to improve quality of life, the efficiency of urban operations and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental, and cultural aspects" [16]. This definition places ICT at the core

of achieving urban sustainability—potentially, however, at the expense of the broader, multidimensional understanding of sustainability [17].

According to Schraven et al. [18], the concepts of the "sustainable city" and "smart city" form a conceptual duopoly, frequently appearing together and highlighting the complexity of their interrelation within sustainable urbanism. Theoretically, the vision of smart cities aligns with the goals of sustainable development [19]. Smart cities oriented toward sustainability offer a pathway to enhance both urban competitiveness and sustainability [20], while also supporting socioeconomic development and addressing environmental challenges [21].

Shao and Min [22] propose a four-pillar framework—environment, society, economy, and governance—to describe and integrate smart cities, further illustrating how these cities embody the principles of sustainability. Moreover, the concept of smart sustainable cities is inherently human-centered, involving the multidimensional integration of people and digital technologies and pointing to the likely trajectory of future urban development worldwide.

A credible and verifiable assessment framework that enables the tracking, analysis, and evaluation of the multidimensional performance of smart city development is a core component of integrated smart city management [23]. While numerous assessment tools for smart cities already exist, the need for more refined frameworks continues to grow as our understanding of smart cities evolves [17].

This raises a critical question: what metrics and standards should be used to evaluate smart and sustainable cities? International organizations such as the International Organization for Standardization (ISO), the International Telecommunication Union Telecommunication Standardization Sector (ITU-T), and the ISO/IEC Joint Technical Committee 1 (JTC 1) have made efforts to standardize the evaluation of smart city performance [24]. Among these, the ITU-T has taken a leading role by developing a standardized definition of smart sustainable cities and coordinating the development of related performance indicators.

The ITU's U4SSC initiative offers one of the most balanced approaches to integrating sustainability and smartness in urban performance assessment [25]. Jointly led by the ITU and the UNECE, U4SSC has developed a comprehensive KPI manual that explicitly links smart city evaluation to the SDGs [26]. These KPIs serve as criteria for the assessment of the contribution of ICT to urban sustainability and smartness, while also providing a standardized framework for cities to conduct self-assessments.

To date, more than 100 cities worldwide have begun implementing the U4SSC KPIs. Designed to ensure consistency and comparability, these indicators help cities to collect standardized data, measure performance, and track progress toward the SDGs. In addition to enabling longitudinal performance evaluations, the KPI framework facilitates the exchange of best practices among cities. Furthermore, these evaluations serve as baselines in measuring urban progress toward achieving the SDGs [27].

The U4SSC KPI framework is built upon four key criteria: comprehensiveness, availability, simplicity, and timeliness. The indicators are designed to cover all essential aspects of a smart and sustainable city. They are quantitative in nature, with historical and current data either readily available or easily collectible. Each indicator is conceptually straightforward and intended to be easily understood by a broad range of urban stakeholders. The framework also emphasizes adaptability, ensuring that indicators can be generated in response to emerging challenges in smart and sustainable urban development.

The KPI framework includes a total of 91 indicators, divided into 54 core and 37 advanced indicators. The core indicators are mandatory for all participating cities and provide a fundamental overview of a city's smartness and sustainability. In contrast, the advanced indicators offer a more nuanced assessment of cities that have implemented more

sophisticated initiatives. Additionally, the indicators are categorized into three thematic groups: smart (20 indicators), structural (32 indicators), and sustainable (39 indicators) (see Table 2) [27].

The U4SSC initiative is conducting case studies in cities worldwide to evaluate the feasibility of its indicators and to support the development of a global smart sustainable city index [28]. Integrating the U4SSC framework into national project evaluations offers a standardized, internationally recognized approach that aligns local implementation with global sustainability benchmarks. This integration ensures that smart city development is not only strategic but also inclusive and globally relevant.

Table 2. KPI structure.

Dimension	Sub-Dimension	Category
Economy	ICT	• ICT Infrastructure • Water and Sanitation • Drainage • Electricity Supply • Transport • Public Sector
	Productivity	• Innovation • Employment
	Infrastructure	• Water and Sanitation • Waste • Electricity Supply • Transport • Buildings • Urban Planning
Environment	Environment	• Air Quality • Water and Sanitation • Waste • Environmental Quality • Public Space and Nature
	Energy	• Energy
Society and Culture	Education, Health, and Culture	• Education • Health • Culture
	Safety, Housing, and Social Inclusion	• Housing • Social Inclusion • Safety • Food Security

Source: Modified based on Smiciklas [27].

2.3. Application of the Theoretical Framework and Data Collection

To answer the research question, this study assesses the extent to which the NSSCP aligns with the 91 KPIs of U4SSC. It gauges the achievement of these KPIs by examining the goals, content, and likelihood of achieving planned outcomes within the NSSCP's 13 projects.

For instance, within the category of "transport", which falls under the "infrastructure" sub-dimension of the "economy" dimension, there exist eight KPIs: public transport network, public transport network convenience, bicycle network, transportation mode share, travel time index, shared bicycles, shared vehicles, and low-carbon emission passenger vehicles. This study conducts a detailed analysis of the definitions, descriptions, and methodologies of these eight KPIs to determine whether the goals, contents, and planned outcomes of Project 2A within the NSSCP align with them.

To conduct this evaluation, this study employed in-depth interviews as the primary data collection method. Through a snowball sampling method, a total of 17 key informants were selected to provide insights into the research questions. To respect the wishes of key informants who requested anonymity, their identities were kept confidential throughout the study. Semi-structured interviews were conducted to ensure the comprehensive collection of essential information, all of which took place in face-to-face settings. In the case of Category 1 projects, which are considered foundational within the NSSCP, two individuals were interviewed per project, while, in Categories 2 and 3, one person was interviewed per project. The interviewees represented officials from 11 organizations, including Category 1—Korea Electronics Technology Institute, Electronics and Telecommunications Research Institute, University of Seoul, Korea Institute of Civil Engineering and Building Technology; Category 2—Korea Transport Institute, Korea Land and Housing Corporation, SK Telecom Co., Ltd., University of Seoul; and Category 3—KT Corporation, Korea Electric Power Corporation, Korea Electronics Technology Institute, Korea Advanced Institute of Science and Technology, Advanced Institute of Convergence Technology, and others. The interview period spanned a total of six months, from May to October 2021.

The results of the analysis indicate that 8 out of the 13 projects within the NSSCP align with 13 of the 91 KPIs set by the U4SSC framework. Specifically, 7 out of 45 KPIs (16%) within the "economy" dimension, 4 out of 17 KPIs (24%) within the "environment" dimension, and 2 out of 29 KPIs (7%) within the "society and culture" dimension were achieved. Table 3 provides a list of the corresponding NSSCP projects that align with the U4SSC KPIs. This study conducts an in-depth analysis of the projects that meet these KPIs across eight categories.

Table 3. The list of KPIs by sector and the corresponding projects in the NSSCP.

Dimension (No. of KPIs)	Sub-Dimension (Total No.)	Category	Relevant KPIs	Definition and Description	Project
Economy (45)	Productivity (2)	Innovation	• R&D Expenditure • Small and Medium-Sized Enterprises	• Research and development expenditure as a percentage of city GDP • Percentage of SMEs	All, 3E
	Infrastructure (6)	Transport	• Public Transportation Network • Public Transportation Convenience • Transportation Mode Share	• Length of public transport network per 100,000 inhabitants • Percentage of the city population that has convenient access (within 0.5 km) to public transport • The percentage of people using various forms of transportation to travel to work	2A
	ICT * (6)	Electricity Supply	• Smart Electricity Meters • Electricity Supply ICT Monitoring	• Percentage implementation of smart electricity meters • Percentage of electricity supply system monitored by ICT	3B

Table 3. *Cont.*

Dimension (No. of KPIs)	Sub-Dimension (Total No.)	Category	Relevant KPIs	Definition and Description	Project
Environment (17)	Energy (1)	Energy	• Electricity Consumption • Residential Thermal Energy Consumption • Public Building Energy Consumption	• Electricity consumption per capita • Residential thermal energy consumption per capita • Annual energy consumption of public buildings	3B
	Environment (5)	Air Quality	• Air Pollution	• Air quality index based on reported values for PM10, PM2.5, NO2, SO2, O3	3A, 2B, 3D
Society and Culture (29)	Education, Health, and Culture (3)	Health	• Electronic Health Records	• The percentage of city inhabitants with complete health records electronically accessible to all health providers	3C, 1A
	Safety, Housing, and Social Inclusion (4)	Safety	• Emergency Service Response Time	• Average response time for emergency services	2B
Inaccessible Field	• **Economy**: ICT Infrastructure, Water and Sanitation, Drainage, Transport, Public Sector/Employment/Water and Sanitation, Waste, Electricity Supply, Buildings, Urban Planning • **Environment**: Water and Sanitation, Waste, Environment Quality, Public Space, Nature • **Social and Culture**: Education, Culture/Housing, Social Inclusion, Food Security				

* The "electricity supply" category in the "economy" dimension is discussed with the "energy" category of the "environment" dimension because the project to be analyzed is the same. Source: Modified based on ITU and UNECE [26].

3. Results

This study analyzed the sectors measurable within the NSSCP and aligned them with the KPIs of the U4SSC framework. The identified sectors include the economy (innovation and transportation), the environment (energy and air quality), and society and culture (health and safety).

3.1. Economy

3.1.1. Innovation

The NSSCP is a large-scale R&D project undertaken as part of a national strategic initiative in South Korea. The project has received a total R&D investment of USD 75.1 billion, combining contributions from the Korean government and the private sector. This investment represents 4.64% of South Korea's GDP, positioning it as the second-largest country in the world, after Israel, with 4.94% of its GDP allocated to R&D [29].

Of this total investment, the Korean government's R&D in the smart city field grew at an average annual rate of 16.8% from 2014 to 2016. This result is based on a search conducted by the Korea Institute of S&T Evaluation and Planning (KISTEP) that identified projects related to smart cities, smart energy, smart buildings, smart transportation, smart safety, and smart administration using the National Science and Technology Information Service (NTIS). In particular, there has been a significant increase since 2015, coinciding with the emergence of the fourth industrial revolution [30].

This R&D project had a budget of approximately USD 118 million, accounting for only 0.15% of the total R&D expenditure. In comparison, the European Union invests over USD 674 million annually in various R&D programs, including the European Innovation

Partnership on Smart Cities and Communities (EIP-SCC) and Horizon 2020. In the United States, private companies lead in technology, while the federal government focuses on developing original technology. The Biden–Harris administration announced plans to invest USD 2 trillion in smart cities, while China has declared an investment of more than USD 421.76 billion in smart cities since 2013. Given these trends and the size of Korea's economy, an annual investment of over USD 252.9 million in developing core technology for smart cities is necessary. Notably, the Korean government's R&D efforts in digital twins, AI of Things (AIoT), cloud–edge computing technology, and urban informatics are still limited [31]. Against this backdrop, this project's significance lies in its contribution to smart technology research and development in various fields, promoting the development of smart cities in Korea.

The 3D project developed smart city business and service models based on the local demands of a demonstration city (Siheung) and promoted new industries using smart city data. A smart city platform was created through the plan, with top-down and bottom-up projects, to provide local governments with various solutions to the problems that they wished to solve, with a strong focus on encouraging SME participation. In total, 14 out of 22 companies participating in the 3E project from 2019 to 2021 were SMEs.

One of the services developed through this initiative was a fine dust monitoring system based on light detection and ranging (LiDAR). This is the first in the world to use scanning LiDAR for ultrafine dust concentration measurements, with a resolution of 30 m and a radius of 5 km. This was developed through a collaboration between two state universities in Busan and Daejeon (Pukyong National University and Hanbat University) and Samwoo TCS Co., Ltd., an SME [32].

Moreover, the project aimed to create a smart daycare center model that addressed the heavy workload of childcare providers and ensured children's safety through the use of smart technology. Three SMEs were involved in the development of this model. It provides AI and IoT-based customized education services that discover infant and toddlers' talents and nurture creative talent suitable for the future society. Characteristic data are collected through intelligent CCTV, tracking technology, and facial recognition technology. Based on these technologies, the model creates a child-centered and play-centered customized childcare environment and prevents accidents. Additionally, it utilizes IoT-based smart devices, such as air purifiers that block fine dust and airborne bacteria and automatic thermal imaging cameras to prevent infection risks and predict health abnormalities. It also creates a comfortable indoor environment by smartly adjusting the heating, cooling, ventilation, and lighting. Finally, the model focuses on providing opportunities for children to grow and commune with nature, addressing the limitations of technology-oriented smart systems [33,34] (see Figure 3).

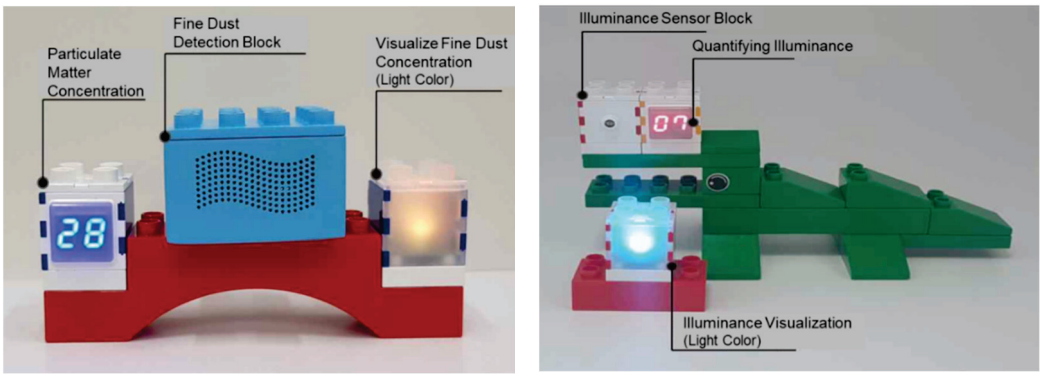

Figure 3. Smart blocks for indoor comfort monitoring. Source: Heerim [35].

3.1.2. Transport

This R&D project placed a significant emphasis on smart transportation. The objective of the 2A project was to improve the convenience of public transportation and personal mobility through smart mobility and parking services and to tackle traffic congestion in the city center by promoting public transportation.

According to the in-depth interview with the Project Manager (PjM) of the 2A project, the smart mobility service provides personalized mobility services based on individual behavioral analysis. It collects and analyzes personal mobile information (such as taxi and private car usage) to identify various patterns of transport demand. It then connects various means of transport, including existing public transport (PT), demand-responsive transport (DRT), and personal mobility (PM), to offer comprehensive mobility services that cover the entire process from booking to use and payment, all tailored to meet the specific demands of the users (see Figure 4).

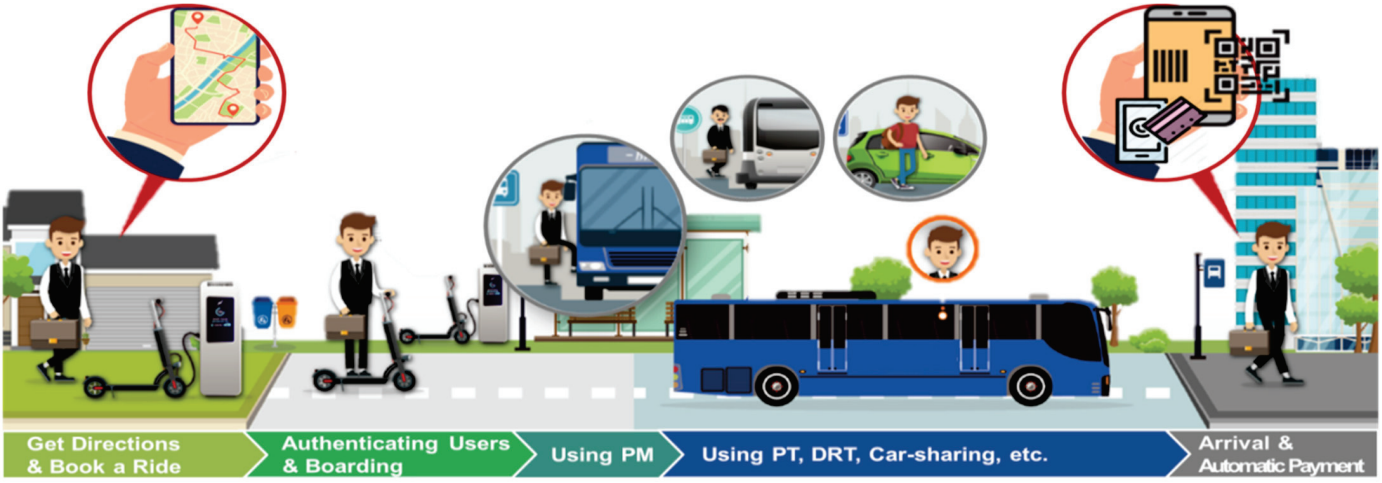

Figure 4. Smart mobility service scenario.

The smart parking service provides customized parking services that maximize the efficiency of parking facilities management using digitalized parking lot information. The project involved developing technologies to collect and integrate real-time parking data from public and private parking lots within the cities, offering technologies to provide and manage real-time parking data, designing the system to develop parking data standards and performance criteria, and analyzing the patterns of parking lot users. It provided customized parking services for users through the Mobility as a Service (MaaS) platform.

These technologies and systems of the 2A project directly improved the length of the public transport network, enabled convenient access to public transport, and increased the percentage of people using various forms of transportation to travel to work. In the long term, they have contributed to increasing the number of shared bicycles or vehicles and the lengths of bicycle paths and lanes and reducing the ratio of the travel time during peak periods to the travel time at free-flow periods.

The public transport network of the U4SSC initiative includes both high-capacity (such as heavy rail, metro, subway systems, and commuter rail systems) and light-capacity (such as light rail streetcars and trams, buses, and trolleybuses) modes of public transport. However, the total length of the public transport system does not necessarily provide accessibility information, and investments in public transport can be more expensive if the needs and demands are not taken into account. For example, the smart mobility service, which is an integrated service with public transportation, shared cars, and PM, can enhance the convenience of the public transport network. Additionally, the demand response

service improves the mobility efficiency. These services increase citizens' public transport network convenience and ensure convenient access.

The percentage of people who use various modes of transportation to travel to work is referred to as the transportation mode share. As congestion is typically the worst during peak hours, when people are driving to and from work, gathering data during these times is crucial in taking action to reduce congestion. The Daegu City empirical case of the 2A project indicated that business, tourism, school transportation, and vulnerable areas of traffic infrastructure were the travel types in the service area. In other words, the system uses various means of transportation for commuting and travel destinations, which are emphasized by the U4SSC initiative, ultimately reducing congestion.

3.2. Environment

3.2.1. Energy

The 3B project sought to enhance the city's energy efficiency through the development of a community energy management system (CEMS) designed for residential homes, commercial buildings, factories, and public facilities. To achieve this, big data and machine-learning-based energy use analysis and demand forecasting technology have been developed. Energy sharing services and systems have also been developed by linking an integrated energy management system (x-EMS) that is optimized for various types of facility operating environments, such as buildings and factories. The x-EMS improves the energy consumption, facility performance, and operation methods and saves energy through the optimal operation of facilities. Depending on the characteristics of the facility, the x-EMS can be applied in various ways, such as a building EMS (BEMS), factory EMS (FEMS), data EMS (DEMS), retail EMS (REMS), smart farm EMS (SEMS), or water EMS (WEMS).

The FEMS and BEMS developed in the project contribute significantly toward reducing the per capita electricity consumption, residential thermal energy consumption, and energy usage of public buildings, aligning with the goals of U4SSC regarding the energy sector. The electricity supply category in the ICT sector is satisfied by presenting smart electricity meters as core indicators and electricity supply ICT monitoring as an advanced indicator. The former enables energy demand management through a smart meter that can measure the load of the power grid and consumers' consumption habits more directly and in real time, while the latter enables the expectation of a stable energy supply by monitoring the power supply through the supervisory control and data acquisition (SCADA) system.

During the comprehensive interview with the PjM of the 3B project, it was revealed that an integrated metering infrastructure had also been developed to enable consumers to monitor their energy consumption comprehensively and efficiently. A platform for the monitoring of energy consumption was developed by detailing the specifications for smart meters that enable integrated meter readings. An integrated metering system based on a smart meter gateway (SMGw) was established to promote energy efficiency through the standardization of five types of energy (electricity, water, gas, heating, and hot water). Providing Smart Metering as a Service (SMaaS), which applies an advanced metering infrastructure (AMI) system based on SMGs to a large amount of metering data, contributes to the expansion of the remote metering of measured data and a reduction in the fixed cost for system construction and operation throughout the country.

To protect users' personal information, the 3B project has developed a National Intelligence Service (NIS) authentication security system. Additionally, to enable an energy marketplace, the project has linked the integrated meter reading infrastructure to the behind-the-meter (BTM) system of the watt-hour meter (WHM), which supplies energy

directly to homes and buildings. This creates an open service platform that shares usage information from various energy sources, including electricity, in real time.

However, in the context of smart sustainable cities, it is important to focus on improving the percentage of electricity supply systems that are monitored by ICT. This can be achieved by establishing SCADA systems to monitor and control the operational status of energy consumption facilities in buildings. Additionally, developing operating technology for optimal energy demand management in buildings will also contribute to improving the overall efficiency of energy consumption. These efforts will help to promote sustainable development and a more cost-effective energy supply system. Ultimately, establishing an integrated urban energy management system and periodically analyzing the effects of energy efficiency services promote energy efficiency.

3.2.2. Air Quality

The 3A project has developed a high-resolution fine particle information system for small-sized cities—specifically Siheung—utilizing ultrafine particle sensing technology and a prediction model based on crowdsourcing. While the Korea Environment Corporation's "Air Korea" provides ultrafine particle information with a 3.5 km resolution every hour, Korea still ranks highly in terms of its fine dust concentrations among OECD countries [36]. Thus, citizens require prompt and detailed information on ultrafine particles to engage in safe outdoor activities. To address this issue, the KT Corporation, South Korea's largest telecommunications company, has developed ultrafine particle sensors (fixed, portable, and deployable) and a prediction model, providing high-resolution ultrafine dust information at 1 km or less every 10 min to policymakers and citizens.

To generate ultrafine particle information, fixed sensors are deployed in a matrix at intervals of less than 1 km, movable sensors are installed in populated areas, and portable sensors are distributed to citizens in living labs. The air quality within citizens' living spaces can be measured using these sensors. Consequently, it is possible to analyze the types of ultrafine dust pollution sources, identify high-risk areas, and improve citizens' quality of life by providing web-based information. According to the thorough interview conducted with the PjM of the 3A project, this system is differentiated from existing ones in that it employs a crowdsourcing-based approach.

The 2B project developed the Massive IoT RF Gateway (GW) and Edge GW to comprehensively monitor, analyze, operate, and control fine dust. For instance, real-time indoor environmental information was measured and monitored for a daycare center in Siheung City. Ventilation equipment was automatically linked with real-time indoor/outdoor environmental information, and an intelligent control system was established. Additionally, the real-time measurement values of the classroom at the daycare center were visually expressed through indoor digital signage. A virtual network was introduced to prevent external malicious access to devices installed in daycare centers. Numerous fine dust sensors were placed in the surrounding areas of the daycare center and in areas where fine dust complaints had been made to measure the outdoor air quality. A massive IoT pilot network was established to collect outdoor air quality measurements.

Additionally, based on the results of an extensive interview with the PjM of 3D, it was revealed that they developed the world's first fine particle monitoring system using scanning LiDAR in response to Siheung City's demand, where industrial complexes are concentrated. This innovative system, as stated by Gwak [32], has the ability to scan ultrafine dust concentrations with a remarkable resolution of 30 m and a radius of 5 km (see Figure 5).

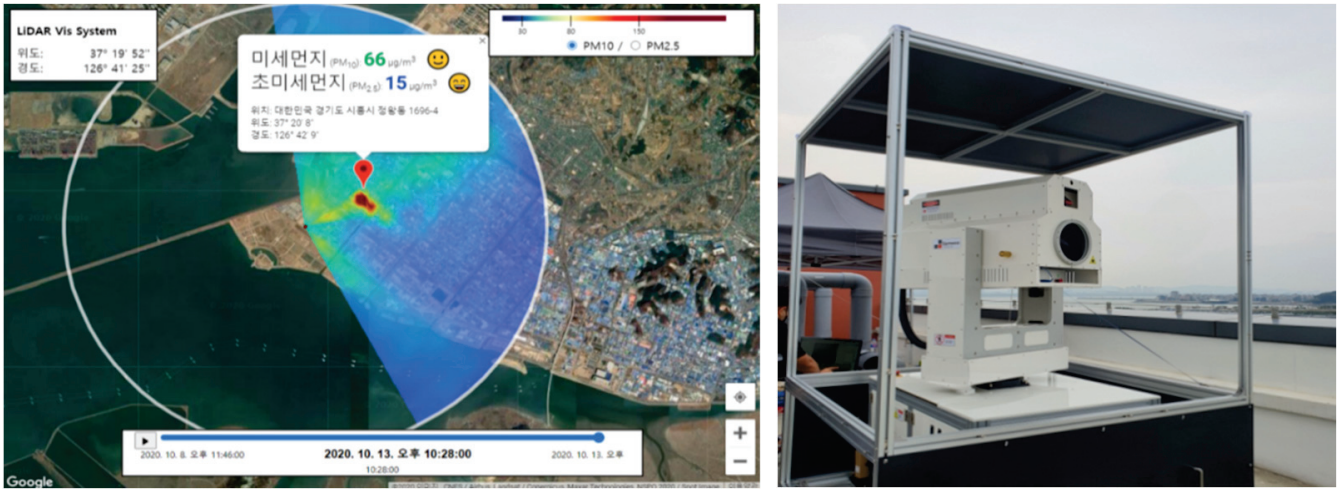

Figure 5. Location-based concentration visualization with the world's first scanning LiDAR particulate matter instrument. **Note:** The center of the visualization displays the concentration of fine and ultrafine particulate matter, shown both as a numerical value and an emoji (e.g., a smiley face) to indicate air quality levels. The bottom of the visualization presents the date and time of the measurement. The collected data are made accessible to both officials and citizens through web pages and mobile applications. Source: Gwak [32].

These technologies help to reduce air pollution, which is prioritized first among the environmental aspects of U4SSC. U4SSC classifies air pollution based on reported values for particulate matter (PM10 and PM2.5), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3) using the air quality index (AQI). In other words, the 3A and 2B projects not only decrease fine dust concentration in the target area but also aid policy measures, such as mapping to identify hotspot areas requiring special attention and supporting people threatened by air quality deterioration. Ultimately, this is a step toward the environmentally sustainable smart city that U4SSC aims to achieve.

3.3. Society and Culture

3.3.1. Health

The detailed interview with the PjM of the 3C project revealed that a total care system had been established and was being operated to enhance the quality of life of vulnerable members of society, such as elderly individuals living alone. The service collects data using non-contact sensors installed in the home of the service users and uses smartphones and wearable devices to manage health conditions and predict dangerous situations among elderly people living alone. Specifically, it (a) provides health counseling and medication management through mobile apps and AI home robots for senior citizens living alone; (b) provides cognitive and emotional improvement programs for the elderly living alone after emergencies such as fires; (c) establishes a biometric data measurement system for chronic disease management in the public health center and branch office; and (d) provides a notification service to related parties by detecting emergencies among single elderly people, such as fires and falls.

In particular, the service manages patient information in cooperation with private companies, local communities, public health centers, and nursing hospitals by setting a local public medical institution as a care base. By providing a service to manage health and safety among the elderly living alone, this project aims to improve the accuracy in the prediction of health conditions, improve the mortality prevention rate, and reduce the lead time in tracking missing persons.

Furthermore, the project aims to enhance the quality of life of people with disabilities by offering a mobility assurance system. This system collects mobility data for the disabled by crowdsourcing; these data are collected and analyzed, and optimal routes and transportation (smart maps) are recommended through the system. To develop a route simulation for the disabled, AR technology was applied to simulate in-building routes, and image information-based mobility simulation technology was developed.

Technology that computerizes health information for vulnerable individuals and responds to emergencies is a means of achieving U4SSC's health goal. The primary KPI in the health category is the percentage of city residents with electronic health records (e-health records). This system collects and stores patients' health records digitally, making them accessible and shareable among all relevant health providers. e-health records contain the latest information on a patient, including visits to healthcare providers, immunizations, imaging results, and billing information, making them invaluable in emergencies, when a patient is unable to communicate.

In conclusion, the technology developed by the 3C project can computerize health records for a specific class, and it provides an emergency response system linked to the local community infrastructure. This system is focused on socially disadvantaged individuals, such as the elderly living alone and the disabled, and it can be a valuable tool in emergencies.

Another technology that computerizes and utilizes a patient's health records is the "Korea Epidemiological Investigation Support System" (K-EISS), which is based on the data hub in the 1A project. This system rapidly obtains the movement routes of confirmed cases by analyzing real-time data such as location and payment information from telecom and credit card companies. It identifies the routes and hotspots of infection by conducting a spatial–temporal analysis of the movement of confirmed patients. Thanks to big data analysis, the system can automatically identify stay points by period and the source of infection in the region by finding a large-scale outbreak area. Previously, it took up to 24 h to conduct an epidemiological investigation of a confirmed COVID-19 case. The Act on the Prevention of Infectious Diseases required the Minister of Health and Welfare (MOHW) to request location information from the National Police Agency (NPA) about the confirmed person. The NPA would then request information from the individual telecommunication company via 18 local police agencies and precincts. However, the K-EISS can implement this process within 10 min through an online batch processing system that includes receiving, approval, and transmission (see Figure 6).

Such a system contributed to reducing the increase in the number of patients due to the global COVID-19 pandemic. In particular, automatic management through computerized records of the confirmed case made it possible to respond rapidly. While the U4SSC initiative raises concerns about sharing patient information, it may only be collected in exceptional or life-threatening situations through the system. Recently, the K-EISS has been bundled worldwide with a QR code-based electronic registry system and the Self-Quarantine Safety Protection Application, called the K-Quarantine Solution.

3.3.2. Safety

Out of the nine safety indicators of U4SSC, seven are mostly related to natural disasters, which include natural-disaster-related deaths, disaster-related economic losses, resilience plans, the population living in disaster-prone areas, emergency service response times, police services, and fire services. In project 2B, the goal is to reduce the average response time for emergency services by developing technology for the early alert of disasters and emergency rescue and response services through data sharing. The aim is to establish an early alert system to collect, analyze, and distribute information on risky situations and

develop emergency rescue and response services to guarantee public safety and minimize the losses caused by disasters.

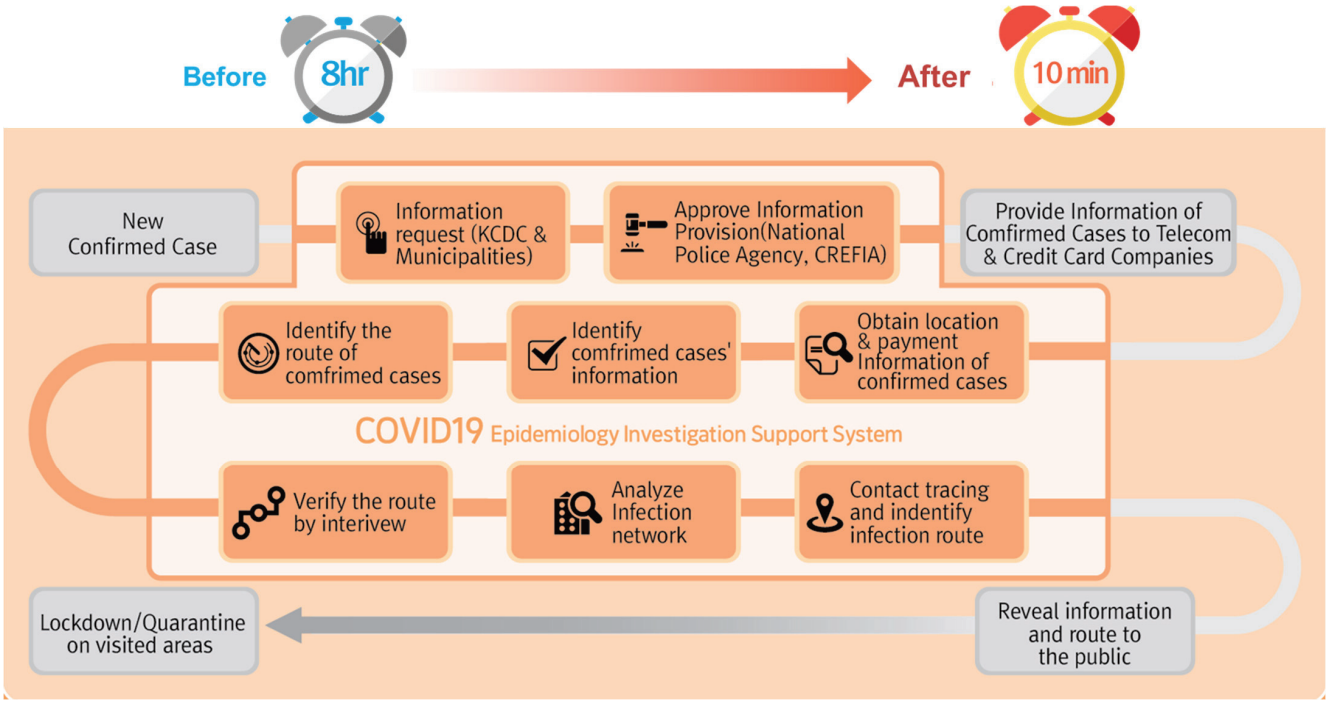

Figure 6. System flowchart of K-EISS. Source: Modified based on MOLIT [12].

Data-driven disaster response systems are in operation, collecting and analyzing data on emergency situations through data platforms, as evidenced in an extensive interview with the PjM of the 2B project. Various data collected through sensors on disasters, such as slope collapses, floods, heatwaves, fires, and accidents, are displayed on the safety platform and data hub. Key analysis results, including disaster forecasts, are delivered to emergency aid and disaster control rooms and distributed to citizens through safety mobile applications. For example, the system provides "location-based real-time flood forecast and alert services" and "automatic rainwater pump and watergate operation services" by linking data from the Korea Meteorological Administration. It has smart services to provide heatwave information (map) and offer mitigation measures. It also classifies fire detection and fire accident hazard areas and services to support the mobilization of emergency rescue activities.

Emergency service response times are an indicator of the effectiveness of these services in responding to emergencies and safeguarding city inhabitants. Emergency services include police, firefighting, and ambulance services, including transport and urgent care. This indicator is often interpreted as the average time (in minutes) taken to respond to emergency calls from the initial call to arrival onsite. Although the project has not yet resulted in direct empirical results in terms of reducing the average time, the ultimate goal is to reduce the loss of lives and property caused by natural disasters such as slope collapses, flooding, and heatwaves by up to 20% and to reach the target of an 80% rate of arrival at the scene of the accident within the critical window.

Table 4 presents an overview of the key findings.

Table 4. Summary of the key findings.

Dimension	Sub-Dimension	Category	Achievements
Economy	Productivity	Innovation	• Expanded R&D activities in the previously underdeveloped smart city sector • Increased SME participation in smart city technology and service development (14 of 22 participating companies are SMEs)
	Infrastructure	Transport	• Enhanced mobility efficiency through integrated, user-tailored services (e.g., PT, DRT, PM connectivity) • Improved usability and accessibility of the PT network • Reduced congestion by promoting multimodal commuting
Environment	Energy	Energy	• Lowered energy consumption and ensured stable supply via smart meters and ICT-based monitoring (e.g., CEMS, BEMS, FEMS)
	Environment	Air Quality	• Delivered air quality data and supported proactive measures using fine dust sensors and prediction model
Society and Culture	Education, Health, and Culture	Health	• Provided welfare and medical services for elderly residents and mobility support for persons with disabilities; digitized health records for vulnerable groups • Developed the K-EISS to enable rapid COVID-19 response
	Safety, Housing, and Social Inclusion	Safety	• Advanced disaster early warning and emergency response technologies through data integration and sharing

4. Discussion and Implications

This study investigated the NSSCP to determine the extent to which South Korea's smart city promotion strategy contributes to sustainable and smart urban development. A comprehensive analysis of the results reveals the following findings. Firstly, the NSSCP has contributed to the achievement of SDGs 3, 7, 9, and 11, with a focus on people (innovation), mobility, energy, the environment, and living. This implies that the NSSCP covers almost all of the fundamental components of smart cities that are widely discussed globally. According to the U4SSC index classification system, 55 core indicators and 36 advanced indicators have been equally satisfied. This demonstrates that Korea's smart city promotion strategy is moving in a sustainable and intelligent direction at an international level (refer to Table 5).

Secondly, the NSSCP employs a cloud-based open data hub architecture model to develop a data-driven smart city. For instance, the data hub model created by the NSSCP is utilized to offer all services in mobility (smart mobility and smart parking), energy (integrated energy management), and healthcare (total care for the elderly living alone). The development of the data hub architecture, as stated by the project manager of 1A, represents a significant step toward the advancement of smart cities.

Table 5. Sustainable and smart city metrics achieved through the NSSCP.

Dimension	Category	KPI	SDGs	
Economy	Innovation	R&D Expenditure	• 9.5.1: Research and development expenditure as a percentage of GDP.	
		Small and Medium-Sized Enterprises	• 9.3.1: Percentage of small-scale industries with total industry value added.	
	Transport	Public Transport Network and Convenience	• 11.2: By 2030, provide access to safe, affordable, accessible, and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities, and older persons.	
		Transportation Mode Share		
	Electricity Supply	Smart Electricity Meters	• 7.3: By 2030, double the global rate of improvement in energy efficiency.	
		Electricity Supply ICT Monitoring		
Environment	Energy	Electricity Consumption	• 7.3: By 2030, double the global rate of improvement in energy efficiency.	
		Residential Thermal Energy Consumption		
		Public Building Energy Consumption		
	Air Quality	Air Pollution	• 11.6: By 2030, reduce the adverse per capita environmental impact of cities by paying special attention to air quality and municipal and other waste management. • 11.6.2: Annual mean levels of fine particulate matter (e.g., PM2.5 and PM10) in cities (population-weighted)	
Society and Culture	Health	Electronic Health Records	• 3.D: Strengthen the capacity of all countries—in particular, developing countries—for early warning, risk reduction, and the management of national and global health risks.	
	Safety	Emergency Services Response Time		

Thirdly, this project lacks a tool to evaluate its outcomes and impacts and has primarily focused on achieving quantitative goals. It has paid less attention to the service quality, and there is no clear technology valuation index to assess the level of the system. It is crucial to establish a differentiation factor and produce unique results that distinguish it from other smart city development projects. Taking a long-term perspective, it is essential to prioritize quality improvement and the expansion of outcomes and outputs.

Globally, 11 of the G20 member countries have introduced national smart city strategies. Most of these strategies emphasize qualitative aspects—such as vision setting, stakeholder engagement, and governance frameworks—over quantitative criteria, including performance evaluation, key performance indicators (KPIs), and monitoring mechanisms [1]. In this respect, South Korea's approach to smart city development diverges from that of many leading smart city nations. While developed countries often promote smart cities through public–private collaboration and data- or platform-centric solutions, developing countries tend to adopt public-sector-driven policies aimed at enhancing national competitiveness and addressing urban challenges. Although South Korea is an OECD member and thus categorized as a developed country, its smart city policy has largely followed a public-led model, more commonly associated with developing countries.

Regional variations in smart city approaches further illustrate these distinctions. In North America and Europe, smart city initiatives frequently leverage open data and living labs to foster citizen participation and enhance quality of life. In contrast, many Asian countries have prioritized the development of urban infrastructure to stimulate industrial ecosystems through emerging technologies—often aligned with the fourth industrial revolution. However, South Korea's approach has been constrained by a limited focus on ecosystem revitalization as an integral element of smart city development.

Recognizing these shortcomings, Korea's 4th Smart City Comprehensive Plan, released in 2024, identifies the need for greater private sector participation in smart city initiatives as a key strategic priority. As the highest-level statutory plan in the field—formulated every five years—it reflects a shift toward more market-driven approaches to complement existing public-led frameworks and address previous implementation challenges.

Nevertheless, the NSSCP exhibits certain limitations. Firstly, it functions as a state-led R&D initiative bolstered by substantial public funding. However, the successful commercialization of this research and development necessitates not only the participation of the central government but also active involvement from local governments. While smart technologies stemming from the NSSCP were implemented in Daegu Metropolitan City and Siheung City, significant challenges arose in data collection and the introduction of these technologies to pilot areas. This predicament arose because each instance required close cooperation between the respective cities and districts. It is crucial to recognize that, while the state can incentivize the development of novel and innovative technologies and spearhead related endeavors, the practical application and widespread adoption of these technologies often prove more effective when spearheaded by private companies and developers, with the cooperation of municipal governments.

One way to address these limitations is by considering the Lighthouse Project in Europe, an EU-funded smart city demonstration initiative implemented across various European cities. At the core of this project is a structured relationship between Lighthouse Cities—which serve as pioneers in deploying smart city technologies—and Fellow Cities, which adapt and replicate the proven solutions demonstrated by the former. Lighthouse Cities could pilot innovative technologies and solutions in real-world urban contexts, while Fellow Cities benefit from the lessons learned and successful practices established by their counterparts, facilitating more efficient and informed adoption. The diffusion process involves active collaboration among city governments, private companies, academic institutions, and research organizations, each contributing their expertise to advance the broader implementation of smart cities across Europe.

While the Lighthouse Project aligns with overarching EU policy objectives, it also emphasizes the development of locally tailored smart city strategies. These strategies respond to specific urban challenges and needs by applying targeted technologies and fostering robust citizen engagement. By responding directly to the needs and problems of

urban communities, smart city technologies have the potential to mitigate critical issues such as social polarization and urban poverty [37]. Moreover, they can serve as instruments to reduce inter-regional disparities and foster balanced territorial development [38].

Importantly, the project extends beyond institutional participation. Citizens are actively involved through urban living labs, where they function not only as the end-users of smart city solutions but also as co-creators. They contribute by identifying local issues, providing feedback, and shaping the development and refinement of applied technologies [39].

Secondly, concerning the CEMS and the standardization of metering systems for the five energy sources (electricity, water, gas, heating, and hot water) developed by the NSSCP, it is imperative to delve into heterogeneous data integration. Energy data have the capacity to amalgamate diverse data types, including those from credit card companies, mobile operators, distributors, and manufacturers, thereby augmenting the data's potential value. The seamless integration of heterogeneous data is essential in harnessing the full potential of smart technologies.

Furthermore, the data hub developed as part of the NSSCP's efforts has exhibited highly favorable characteristics. For example, it was instrumental in the creation of the K-EISS, which played a critical role in effectively managing the COVID-19 outbreak and had a significant impact. Nonetheless, the imperative of safeguarding patients' personal health information looms as a matter that requires future attention and resolution. Additionally, regarding early warning systems and emergency response services for natural disasters and catastrophic events, optimal data sharing will be realized when a clear consensus emerges regarding the integrated utilization of the system among relevant organizations, such as the Korea Meteorological Administration, the Ministry of Public Administration and Security, the National Police Agency, the National Fire Agency, and healthcare institutions.

While technology plays a critical role in the development of smart cities, not all smart city services are inherently technology-driven. The strategic integration of both technology-based and non-technology-based solutions can enhance urban performance and significantly improve residents' quality of life [40]. Mondschein et al. [41] highlight that the primary challenges faced by policymakers—who are central stakeholders in the deployment of smart technologies—are often organizational rather than technological. This underscores the importance of stakeholder alignment as a key factor in the successful implementation of smart city initiatives. As noted by Kim et al. [42], "smartness" encompasses a broad spectrum of dimensions beyond technological innovation. Therefore, it is essential to recognize that smart cities are not solely defined by the presence of advanced technologies.

5. Conclusions

This research contributes to the field from three perspectives. Firstly, the analysis of the NSSCP project offers valuable insights into the current state of smart city development in South Korea. Despite the numerous smart city cases and practical experiences worldwide, the discussion surrounding smart cities in South Korea gained substantial momentum only after the NSSCP's launch in 2018, as noted by Hwang and Shim [43]. This underscores the NSSCP's pivotal role in shaping South Korea's smart city development landscape. Moreover, the limited existing academic discourse on this project underscores the significance of this study in contributing to the smart city literature. Therefore, evaluating the project's effectiveness using globally recognized evaluation criteria becomes highly meaningful as it expands the discourse on smart cities in South Korea and provides insights for future development pathways.

Secondly, this study could contribute to the development of sustainable smart cities as it highlights how the NSSCP represents a shift from a technology-centric smart city

paradigm to a human-centric one, as observed by Lee [44]. The NSSCP is committed to analyzing human characteristics and their needs, rather than solely focusing on the development and deployment of smart city technologies or data platforms, utilizing methods such as use case and living lab approaches.

Lastly, the NSSCP marks the inaugural attempt to standardize data hubs on a nationwide scale. Most projects have primarily concentrated on local demonstrations, resulting in data fragmentation and hindering the efficiency of smart cities. The establishment of a standardized open data hub architecture creates a common foundation for transparent and shareable administrative services and fosters the digital economy. Ultimately, this data-driven and inclusive smart city model can be replicated in other urban settings, addressing diverse urban challenges. In this way, the NSSCP proposes forward-looking applications of smart city technologies.

Through the NSSCP, new policy strategies can be identified to help South Korean smart cities to generate greater economic and industrial opportunities. One limitation of this study is that, due to the short duration of the construction of the demonstration city, there are insufficient data to assess the performance of smart technologies and systems. Only when there are enough data to verify the accuracy of smart technologies will it be possible to clearly measure the degree of "digitalization" of a smart city. Measuring digitalization is a crucial undertaking as it allows for the evaluation of the potential benefits and risks associated with the adoption of smart technologies. Policymakers and industry leaders can leverage such assessments to identify areas for improvement in the adoption and implementation of smart technologies. Furthermore, this can facilitate the establishment of benchmarks to evaluate the efficacy of policies and initiatives aimed at promoting the development and adoption of smart technologies. In essence, the measurement of digitalization for smart technologies is imperative in offering valuable insights into their adoption, diffusion, and effectiveness. These insights can subsequently inform policymaking and industry decisions. This finding opens avenues for future research.

After conducting a comprehensive analysis of all aspects of the NSSCP, it becomes evident that the Korean government's smart city project is progressing toward the goal of creating a sustainable and smart city. However, this research also reveals that many of the U4SSC indicators are not addressed within the project. This implies that the NSSCP does not inherently encompass all aspects of what the United Nations defines as sustainable and smart cities. Additionally, numerous technologies and services have already been developed in other projects, such as the nationwide implementation of a dynamic public transport information system. Hence, conducting a comparative analysis with other smart city projects in Korea would be valuable in determining whether Korea is advancing toward becoming a sustainable smart city in the future.

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References

1. Zelt, T.; Mourtada, R.; Genillard, L.; Schober, L.; Sieg, M. Building National Momentum for the Smart-City Agenda. Available online: https://www.bcg.com/publications/2023/advancing-the-smart-city-agenda-nationally (accessed on 31 March 2025).
2. Cai, M.; Kassens-Noor, E.; Zhao, Z.; Colbry, D. Are Smart Cities More Sustainable? An Exploratory Study of 103 U.S. Cities. *J. Clean. Prod.* **2023**, *416*, 137986. [CrossRef]
3. Toli, A.M.; Murtagh, N. The Concept of Sustainability in Smart City Definitions. *Front. Built Environ.* **2020**, *6*, 496662. [CrossRef]
4. Trindade, E.P.; Hinnig, M.P.F.; da Costa, E.M.; Marques, J.S.; Bastos, R.C.; Yigitcanlar, T. Sustainable Development of Smart Cities: A Systematic Review of the Literature. *J. Open Innov. Technol. Mark. Complex.* **2017**, *3*, 1–14. [CrossRef]
5. Shvetsova, O.; Bialevich, A.; Kim, J.; Voronina, M. Behavioral Model Deployment for the Transportation Projects within a Smart City Ecosystem: Cases of Germany and South Korea. *Processes* **2022**, *11*, 48. [CrossRef]
6. Korea Agency for Infrastructure Technology Advancement. Smart City Global Journal 2023: Smart City Top Agenda. 2023. Available online: https://smartcity.go.kr/wp-content/uploads/2023/03/%EC%8A%A4%EB%A7%88%ED%8A%B8%EC%8B%9C%ED%8B%B0-%ED%83%91%EC%95%84%EC%A0%A0%EB%8B%A4-%EC%A0%80%EB%84%90-2023_%EC%98%81%EB%AC%B8.pdf (accessed on 26 January 2025).
7. Yang, J.; Kwon, Y.; Kim, D. Regional Smart City Development Focus: The South Korean National Strategic Smart City Program. *IEEE Access* **2021**, *9*, 7193–7210. [CrossRef]
8. Lim, S.-M.; Kim, S.-S. A Study on the Introduction and Operation of Stage-Gate Process for Performance Management in National R&D Projects -Focused on the National Strategic Smart City Program. *J. Korea Acad.-Ind. Coop. Soc.* **2020**, *21*, 226–232. [CrossRef]
9. Patrão, C.; Moura, P.; de Almeida, A.T. Review of Smart City Assessment Tools. *Smart Cities* **2020**, *3*, 1117–1132. [CrossRef]
10. Li, C.; Dai, Z.; Liu, X.; Sun, W. Evaluation System: Evaluation of Smart City Shareable Framework and Its Applications in China. *Sustainability* **2020**, *12*, 2957. [CrossRef]
11. Ministry of Land, Infrastructure and Transport. Smart City Korea. Available online: https://smartcity.go.kr/%EC%86%8C%EA%B0%9C/ (accessed on 31 March 2025).
12. Ministry of Land, Infrastructure and Transport. *The 3rd Smart City Comprehensive Plan 2019–2023*; Ministry of Land, Infrastructure and Transport: Sejong, Republic of Korea, 2020.
13. Ministry of Economy and Finance. Announcement of "Korean Version of New Deal 2.0 Action Plan" by the Relevant Ministries. Available online: https://www.moef.go.kr/nw/nes/detailNesDtaView.do;jsessionid=Hlmgc1PK9F3IN4DAtZphLAht.node60?searchBbsId1=MOSFBBS_000000000028&searchNttId1=MOSF_000000000055824&menuNo=4010100 (accessed on 31 March 2025).
14. KAIA. *Advancement Annual Report: National Strategic Smart City Program*; Korea Agency for Infrastructure Technology: Seoul, Republic of Korea, 2019.
15. Soe, R.M.; Schuch de Azambuja, L.; Toiskallio, K.; Nieminen, M.; Batty, M. Institutionalising Smart City Research and Innovation: From Fuzzy Definitions to Real-Life Experiments. *Urban Res. Pract.* **2022**, *15*, 112–154. [CrossRef]
16. International Telecommunication Union. *A UN Initiative*; International Telecommunication Union: Geneva, Switzerland, 2021.
17. Qian, X.; Chen, M.; Zhao, F.; Ling, H. An Assessment Framework of Global Smart Cities for Sustainable Development in a Post-Pandemic Era. *Cities* **2024**, *150*, 104990. [CrossRef]
18. Schraven, D.; Joss, S.; de Jong, M. Past, Present, Future: Engagement with Sustainable Urban Development through 35 City Labels in the Scientific Literature 1990–2019. *J. Clean. Prod.* **2021**, *292*, 125924. [CrossRef]
19. Kaika, M. 'Don't Call Me Resilient Again!': The New Urban Agenda as Immunology or What Happens When Communities Refuse to Be Vaccinated with 'Smart Cities' and Indicators. *Environ. Urban* **2017**, *29*, 89–102. [CrossRef]
20. Giffinger, R.; Lu, H. *The Smart City Perspective: A Necessary Change from Technical to Urban Innovations*; Fondazione Giangiacomo Feltrinelli: Milan, Italy, 2015; ISBN 978-88-6835-104.
21. Yigitcanlar, T.; Dur, F.; Dizdaroglu, D. Towards Prosperous Sustainable Cities: A Multiscalar Urban Sustainability Assessment Approach. *Habitat Int.* **2015**, *45*, 36–46. [CrossRef]
22. Shao, J.; Min, B. Sustainable Development Strategies for Smart Cities: Review and Development Framework. *Cities* **2025**, *158*, 105663. [CrossRef]
23. Westraadt, L.; Calitz, A. A Modelling Framework for Integrated Smart City Planning and Management. *Sustain. Cities Soc.* **2020**, *63*, 102444. [CrossRef]
24. Lee, J.G. The Trends of Smart City International Standardization. *Electron. Telecommun. Trends* **2019**, *33*, 86–90.
25. Huovila, A.; Bosch, P.; Airaksinen, M. Comparative Analysis of Standardized Indicators for Smart Sustainable Cities: What Indicators and Standards to Use and When? *Cities* **2019**, *89*, 141–153. [CrossRef]
26. ITU and UNECE. *Collection Methodology for Key Performance Indicators for Smart Sustainable Cities*; United Nations Economic Commission for Europe: Geneva, Switzerland, 2015.
27. Smiciklas, J. U4SSC Key Performance Indicators for Smart Sustainable Cities. In Proceedings of the 9th Green Standards Week, Valencia, Spain, 1–4 October 2019.

28. International Telecommunication Union. *Key Performance Indicators Project for Smart Sustainable Cities to Reach the Sustainable Development Goals (SDGs)*; International Telecommunication Union: Geneva, Switzerland, 2018.
29. Kim, Y.S. South Korea Has 89 Trillion in R&D Investment Last Year. It Ranks Second in The World with 4.64% of GDP. Chosun Biz. 2020. Available online: https://biz.chosun.com/site/data/html_dir/2020/12/09/2020120900838.html#:~:text=%EA%B3%BC%ED%95%99%EA%B8%B0%EC%88%A0%EC%A0%95%EB%B3%B4%ED%86%B5%EC%8B%A0%EB%B6%80%20%EC%84%B8%EC%A2%85,%EC%84%B8%EA%B3%84%202%EC%9C%84%20%EA%B7%9C%EB%AA%A8%EB%8B%A4 (accessed on 31 March 2025).
30. Ban, S.K. KThe Government R&D Investment in the Smart City Sector Increased by an Average of 16.8% per Annum over the Past Three Years. *Korea Spec. Constr. Assoc. J.* Available online: http://www.koscaj.com/news/articleView.html?idxno=107334 (accessed on 31 March 2025).
31. Moon, B.K. Smart City in Daily Life—Interview with the Director of the National Strategic Smart City Program. etnews. 22 November 2020; p. 5. Available online: https://www.etnews.com/20201120000140?m=1 (accessed on 31 March 2025).
32. Gwak, J.W. Siheung City Showcases World's First Scanning LiDAR Fine Dust Management System Demonstration. Available online: http://www.siheung.go.kr/media/bbs/view.do?bIdx=124378&ptIdx=82&mId=0100000000 (accessed on 31 March 2025).
33. Ha, J.S. Heerim Consortium and Siheung City Create a 'Smart Daycare Center' that Leads the Fourth Industrial Revolution. *Kukto Ilbo*, 25 June 2020. Available online: https://www.ikld.kr/news/articleView.html?idxno=219709 (accessed on 31 March 2025).
34. Heerim. Smart Child Care Center: Development and Demonstration. Available online: https://www.heerim.com/en/expertise/rni_detail.php?idx=4618 (accessed on 31 March 2025).
35. Heerim. Annual Report: Smart Child Care Center: Development and Demonstration. 2020, *Unpublished work*.
36. IQAir. World Air Quality Index (AQI) Ranking. Available online: https://www.iqair.com/us/world-air-quality-ranking (accessed on 31 March 2025).
37. Lee, Y.; Han, S. Exploring Urban Housing Disadvantages and Economic Struggles in Seoul, South Korea. *NPJ Urban Sustain.* **2024**, *4*, 21. [CrossRef]
38. Lee, Y.; Han, S. Mapping the Landscape of Land Inequality: A Multi-Level, Data-Driven Exploration of Land Inequality in South Korea's Urban and Regional Spheres. *PLoS ONE* **2025**, *20*, e0320252. [CrossRef]
39. Lange, K.; Knieling, J. EU Smart City Lighthouse Projects between Top-Down Strategies and Local Legitimation: The Case of Hamburg. *Urban Plan* **2020**, *5*, 107–115. [CrossRef]
40. Keshavarzi, G.; Yildirim, Y.; Arefi, M. Does Scale Matter? An Overview of the "Smart Cities" Literature. *Sustain. Cities Soc.* **2021**, *74*, 103151. [CrossRef]
41. Mondschein, J.; Clark-Ginsberg, A.; Kuehn, A. Smart Cities as Large Technological Systems: Overcoming Organizational Challenges in Smart Cities through Collective Action. *Sustain. Cities Soc.* **2021**, *67*, 102730. [CrossRef]
42. Kim, H.M.; Sabri, S.; Kent, A. Smart Cities as a Platform for Technological and Social Innovation in Productivity, Sustainability, and Livability: A Conceptual Framework. In *Smart Cities for Technological and Social Innovation: Case Studies, Current Trends, and Future Steps*; Kim, H.M., Sabri, S., Kent, A., Eds.; Academic Press: London, UK, 2021; pp. 9–28. ISBN 9780128188866.
43. Hwang, S.; Shim, J. Semantic Network Analysis of "Smart City" in Newspaper Articles-From 2016 to 2019. *J. Digit. Contents Soc.* **2020**, *21*, 941–950. [CrossRef]
44. Lee, T.H. Smart City Business Promotion Direction Through the Case of the National Strategic Smart City Program. IT Daily. 1 November 2020. Available online: https://www.itdaily.kr/news/articleView.html?idxno=200084 (accessed on 31 March 2025).

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Review

Land Expropriation: A Necessary Step to Achieving Economic Inclusivity, Social Equity and Spatial Justice in South Africa

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Abstract

This study critically engages the ongoing national conversation and policy discourse on land expropriation without compensation in South Africa, offering both analytical insight and a principled position. It presents a qualitative, normative-analytical inquiry grounded primarily in critical documentary analysis of legislation, jurisprudence, and land reform scholarship. The study situates the contemporary debate within South Africa's broader historical and structural context, where patterns of land dispossession continue to shape persistent spatial inequality and exclusion. The analysis proceeds from the premise that meaningful urban spatial transformation cannot be realised without addressing the structural constraints embedded within existing land governance and spatial planning systems. In this regard, debates around land expropriation are not simply questions of property law or economic policy but are fundamentally connected to broader concerns of spatial justice, economic inclusion, and social equity. These concerns are particularly salient when considering emerging imaginaries of African urban futures, including the notion of the Pan-African City—an urban formation envisioned as spatially integrated, socially inclusive, and reflective of shared continental aspirations for equitable development. The central argument advanced in this study is that unless South Africa gives serious and programmatic attention to land expropriation—moving beyond token or partial policy measures—the structural conditions necessary for such inclusive urban futures will remain unattainable. In this sense, any vision of a Pan-African City within South Africa's borders risks remaining short-lived, if not altogether specious. To fully engage this debate, the paper unpacks and interrelates the concepts of land expropriation, compensation, expropriation without compensation, economic inclusivity, social equity, spatial justice, and the Pan-African City. These concepts cannot be adequately understood independent of the distinctly South African context—a context shaped by a history of racialised dispossession, deeply entrenched spatial inequalities, and the limitations of both first-generation (restitution, redistribution, tenure reform) and second-generation (e.g., the Spatial Planning and Land Use Management Act) land reform initiatives. The point advanced is unequivocal: without resolving the land question, sustainable housing and human settlement solutions in South Africa will not materialise. Anything less risks entrenching a democratic façade atop an unresolved colonial, segregationist, and apartheid foundation.

Keywords: land expropriation; compensation; economic inclusivity; social equity; spatial justice; Pan-African City

1. Introduction

The question of land ownership in South Africa continues to be among the most enduring and contentious legacies of its colonial, segregationist, and apartheid past. Through successive waves of dispossession—formalised in measures such as the Natives Land Act of 1913 and reinforced by apartheid-era spatial planning—Black people[1] were systematically denied access to land and economic opportunity. By the late 20th century, over 87 percent of arable land had been designated for the White minority, while the Black majority was restricted to overcrowded, underdeveloped, and often economically barren areas.

Although apartheid officially ended in 1994, and South Africa adopted a democratic Constitution that guarantees equitable access to land [1], the geographies of dispossession have not fundamentally shifted. Asymmetrical landownership continues to mirror the racial hierarchies of the past. Thirty years into democracy, the land question serves as a barometer of deferred liberation and a structural fault line in the post-apartheid project.

Efforts at land reform have been cautious, technocratic, and predominantly market driven. The "willing buyer, willing seller" model has proven profoundly inadequate in addressing South Africa's deep-rooted land inequalities. Despite decades of post-apartheid policy efforts, vast numbers of people remain landless or trapped in conditions of insecure tenure.

According to the Presidential Advisory Panel [2], only 8.4 million hectares of land were transferred to Black ownership between 1994 and March 2018—accounting for under 10 percent of the country's commercial agricultural land [3,4]. Although figures differ across sources, certain facts are undeniable: progress has been alarmingly slow, and these failures are not just design- and governance-related but also inherently political and moral. They reflect the limitations of neoliberal reform strategies in addressing historical injustices and expose the enduring power of a racialised agrarian and spatial order that continues to reproduce poverty, inequality, and exclusion.

Within this problematic market-led framework, the state has positioned itself as a "willing buyer" [5], constrained by the pace and terms set by private landowners. Rather than disrupting unjust property relations, the state has too often acquiesced to them, reinforcing the logic that land redistribution must occur on a commercial, consensual basis—even when this delays or derails transformation. This posture reflects not only a policy choice but a broader political orientation that prioritises market stability over social justice, thereby limiting the transformative potential of land reform.

This study contends that the maldistribution of land is not simply a historical aberration to be corrected, but a continuing legacy of inequality that must be dismantled through decisive, redistributive action. Land holds significance beyond purely economic value. It embodies livelihood ("*ukufuya*"), identity ("*lobola*"), and dignity ("*ubuntu*"). Therefore, land reform must be seen not only as a process of restitution ("fixing past disparities") but also as a vital step in social transformation ("fixing present disparities").

The assertion is that land expropriation, including without compensation, is not just legally justifiable but also necessary. Market-led and incremental reforms have failed to deliver meaningful justice or inclusion at scale. It is time for a shift in approach: one that puts justice at the centre, challenges hoarded privilege and redefines land as a public good instead of a commodity.

This study argues that land reform is not just framework-related or bureaucratic, but also deeply political. In many ways, it represents a critical yet unresolved dimension of South Africa's freedom struggle. This study asks: Under what constitutional, ethical, and spatial justice conditions can land expropriation without compensation (EWC) be justified as a necessary instrument for achieving economic inclusivity, social equity, and spatial justice in post-apartheid South Africa? Without bold, programmatic, and rights-based

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expropriation, the promises of democracy will amount to little for millions. The land question, in this sense, is central to achieving true social and political emancipation.

This study is positioned as a normative-analytical and conceptual contribution rather than an empirical study. It advances a constitutionally grounded argument, drawing on documentary sources and interdisciplinary theory to interrogate the legal, ethical, and spatial dimensions of land expropriation in South Africa. In addition to its constitutional and policy analysis, this study introduces and develops the concept of the "Pan-African City" as a normative and conceptual framework through which to reimagine urban land justice in post-apartheid South Africa. Drawing on traditions of Pan-African political thought, African urban scholarship, and decolonial spatial theory, the concept is used not as a formally established planning doctrine, but as an analytical device to foreground questions of ownership, belonging, dignity, and spatial democracy in African cities. By linking land expropriation to this broader urban vision, the study situates land reform within debates on decolonial urban transformation and spatial justice.

2. Methods and Materials

This study adopts a qualitative research design grounded in critical documentary analysis. As indicated in Table 1, this research is anchored in the systematic examination of primary legal texts (including the Constitution of the Republic of South Africa, 1996, the Expropriation Act of 2024, the Spatial Planning and Land Use Management Act of 2013 (SPLUMA), and relevant land reform statutes), Constitutional Court judgments, official government reports (such as the Presidential Advisory Panel and High-Level Panel reports), and peer-reviewed academic literature in the fields of land studies, political economy, constitutional law, and urban planning. These sources were purposively selected based on their direct relevance to land reform, expropriation, and spatial justice in the South African context. Documentary analysis was considered appropriate given that the central research question concerns constitutional interpretation, policy evolution, and normative justification rather than empirical measurement. The method enables a historically grounded and legally informed interrogation of how land expropriation—particularly EWC—is framed within statutory, judicial, and scholarly discourse.

Table 1. Core Documentary Sources Analysed in the Study.

Category	Examples of Sources	Purpose in the Study
Legislation	• Expropriation Act • Constitution of the Republic of South Africa • SPLUMA	To analyse the legal framework governing land reform and expropriation
Policy documents	• Breaking New Ground (BNG) Housing Policy • National human settlements policies • Land reform policy documents	To examine policy approaches to spatial transformation and land redistribution
Academic literature	• Peer-reviewed scholarship on land reform, spatial justice, and urban transformation in South Africa	To situate the study within existing theoretical and empirical debates
Judicial and constitutional interpretation	• Constitutional jurisprudence and legal commentary on Section 25 of the Constitution	To interpret legal debates regarding property rights and expropriation

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The analysis is guided by an interpretive and critical-analytical framework drawing on theories of transformative constitutionalism, distributive justice, and post-colonial political economy. Rather than conducting a systematic literature review, the study undertakes a structured thematic analysis of selected texts to identify recurring legal principles, policy tensions, and conceptual linkages between land reform, economic inclusivity, social equity, and spatial justice. Particular attention is paid to the interaction between constitutional provisions (notably Sections 9, 25, and 26), judicial interpretation, and planning legislation in shaping the scope of lawful expropriation. This approach allows the study to move beyond descriptive policy review and instead offer a normative and theoretically grounded assessment of the conditions under which EWC can be justified as a constitutionally compliant and socially transformative instrument in post-apartheid South Africa.

This study does not rely on primary empirical data collection; instead, it undertakes a critical and interpretive analysis of existing legal, policy, and scholarly materials.

3. Historical and Geographical Context

Making sense of South Africa's land crisis today requires reckoning with a long, painful history characterised by racial dispossession and spatial engineering, whose legacy continues to shape the country's economic, social and spatial realities. This was not fortuitous but central to how power and privilege were built and maintained. The debate over expropriation, especially without compensation, is neither new nor sudden. It is an inevitable response to centuries of state-sanctioned land grabbing and forced removals under colonialism, segregation, and apartheid—or what one commentator referred to as "the hard, necessary, often ugly work of repair" (MSNBC, *Reshaping the Narrative about Afrikaner Farmers in America*).

From the formation of the first colonial settlement in 1652 and its subsequent expansion, successive settler regimes constructed an evolving, punitive legal framework to deprive Black people of land and deny them ownership, tenure security, and spatial autonomy. This framework culminated in the Natives Land Act of 1913, which forced Africans to give up 3.56 million hectares of land in their possession in the "White areas" and prohibited them from buying or renting land outside demarcated "native reserves." At the time, Africans made up 67.5 percent of the national population, yet these reserves accounted for only 7.3 percent of the country's land area, or 9.562 million hectares. Just over two decades later—by which time they comprised 73 percent of the national population—this allocation was only marginally increased, at least on paper, to 12.4 percent, or 15.733 million hectares [6].

Far from being a neutral administrative measure, the Act functioned as both a tool of economic exclusion and a mechanism of social control, displacing African communities from fertile, strategically located lands to overcrowded, unproductive margins. This forced dependency on White-owned commercial farms and urban labour markets was a central feature of racial capitalism [7]. The Act criminalised African land ownership, institutionalised racialised tenure, and laid the legal foundations for territorial apartheid [8,9].

The Group Areas Act of 1950 extended this regime into urban space, entrenching racial zoning and forcibly removing millions of Africans, Coloureds, and Indians from areas designated for "Whites only." For example, by 1980, while one out of every three Indian families had been evicted from their homes under the specific provisions of the Act, only one out of every hundred White families experienced the same. These removals were not accidental; they were central to a broader strategy of spatial exclusion, economic marginalisation, and political disempowerment [10].

These laws and their implementation were far more than administrative regulations. They functioned as instruments of state violence, legitimised by a distorted version of

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the rule of law that prioritised White settler entitlements over indigenous sovereignty. The result was the consolidation of White economic and political power through brazen, unchecked territorial domination enforced by law, coercion, and surveillance.

The cumulative effect was the near-total erasure of Black land rights, stripping the majority not only of access to land, but also of economic autonomy, social dignity, and citizenship rights. It is in this context that EWC must be understood—not as a drastic break from the past, but as a long-overdue response to centuries of spatial and economic pilfering.

The legacy of these historical land laws is not confined to the past; it is visibly and materially embedded in the present-day geography of South Africa. The spatial ordering of inequality continues to define both rural and urban life, reproducing dispossession in new forms and under different legal and economic guises.

In rural South Africa, the apartheid state formalised the Bantustan system through the Promotion of Bantu Self-Government Act of 1959 and related legislation, fragmenting the country into nominally autonomous territories. These so-called "Bantustans" or "homelands" were severely underdeveloped, ecologically degraded, and lacked essential infrastructure such as electricity, industry, or reliable transport. Far from fostering genuine self-governance, these territories functioned as labour reservoirs, subsidising White-owned capital through the supply of cheap, exploitative migrant labour. As one observer put it, they were "areas drained of their menfolk, for their chief export is labour," with men working in White-owned mines and farms in the White areas, while women and the elderly were left behind in the Bantustans to survive on "a primitive agriculture incapable of providing even subsistence" [11]. Although Hendrik Verwoerd, the architect of apartheid, sardonically described this as "a policy of good neighbourliness," the system effectively manufactured statelessness, denying Africans full citizenship and entrenching spatial retribalisation under the guise of ethnic self-determination.

Post-1994, while the Bantustans were legally dismantled, their spatial and governance legacies endure. Many of these areas continue to suffer from insecure tenure, weak infrastructure, and opaque land administration, often governed by traditional authorities whose power has been reaffirmed—rather than transformed—by post-apartheid legal frameworks [12]. These tenure systems not only limit economic participation but also perpetuate gender inequality and political marginalisation.

In urban contexts, the apartheid spatial blueprint persists through zoning laws, transport inequity, informal settlements, and speculative land markets. Despite progressive post-1994 laws such as SPLUMA, cities remain acutely segregated, with the working class and poor relegated to outlying, under-serviced areas. These settlements are not only underdeveloped but are often deliberately obscured from view, reflecting the state's ongoing concern with urban conformity and order rather than inclusion [13]. At the same time, while municipal spatial plans promote ideals of urban compaction and integration, these goals remain largely unrealised due to municipalities' limited capacity to control infrastructure provision or coordinate effectively with other government spheres and private sector actors [14]. Inner-city spaces, meanwhile, are increasingly commodified, reflecting a logic of market exclusion rather than constitutional inclusion.

This is not simply a technical planning problem; it is a constitutional crisis. Section 25(5) of the Constitution guarantees every citizen the right to have access to land on an equitable basis, while Section 26 upholds the right to have access to adequate housing. Yet both are routinely undermined by legal fragmentation, policy incoherence, and a lack of political will. The urban land question thus becomes a mirror of the rural one: both are shaped by a history of exclusion and a present defined by inaction.

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The geography of exclusion in South Africa is neither accidental nor incidental. It is the physical legacy of colonial conquest, racial capitalism, and apartheid engineering. Undoing this legacy will take more than just redistribution. The situation demands what may be termed "redisruption": the intentional and active dismantling of spatial inequality through decisive legal, political, and economic interventions to realise cities and rural landscapes that are just, inclusive, and free. For this, EWC is fundamental.

4. Conceptual Framework

This study draws on interdisciplinary perspectives from key land studies, structural inequality theory, and post-colonial political economy. These strengthen the argument that land expropriation is not just another policy choice, but a critical tool for advancing redistributive justice, reshaping the economy, and deepening democracy. Within this framework, the idea of the Pan-African City is developed as a normative urban construct that synthesises principles of land justice, decolonial spatial restructuring, and collective ownership. It is positioned within ongoing debates in African urban theory and the "right to the city" tradition, and functions as a forward-looking application of the constitutional and redistributive arguments advanced in this study.

Crucial to this framework is the understanding that land in South Africa has always been more than a resource. It is a site of power and prestige, a symbol of citizenship and being, and an arena of historical contestation [15]. The current spatial and economic order did not arise organically; it was constructed through violence, legal exclusion, and racialised dispossession. Restoring land to those dispossessed is therefore not simply restitution—it is structural reconstitution, aimed at reforming the foundations of economic and social participation.

Land reform is thus situated within broader debates about distributive justice [16], transformative constitutionalism [17], and post-colonial state-building. This approach also recognises the limits of market-based models in delivering justice in highly unequal, post-conflict societies. Informed by these traditions, the following sections interrogate the legal, political, and ethical dimensions of land expropriation as a means of transformation.

4.1. Land Expropriation

Land expropriation refers to the state's lawful acquisition of private property, typically for a public purpose or in the public interest. Globally, this mechanism has been used to support infrastructure development, conservation, and urban growth. In South Africa, however, expropriation must be understood within the distinct necessity of redressing centuries of racialised land dispossession [15,18].

In democratic South Africa, expropriation serves both utilitarian and transformative aims. It seeks to reverse the structural legacies of conquest and apartheid planning, enable equitable access to land and resources, and foster broader socio-economic inclusion for historically marginalised groups. In this sense, it functions as an avenue to restorative justice and nation-building.

The legal foundation for expropriation lies in Section 25 of the Constitution, which protects property rights while mandating land reform. Section 25(2) allows the state to expropriate property "for a public purpose or in the public interest," and Section 25(3) requires compensation to be "just and equitable," considering factors such as the history of acquisition, current use, and the purpose of the expropriation [1].

The Provision of Land and Assistance Amendment Act of 2008 [19], which revised the original 1993 Act, aimed to allow the state to acquire, hold, and allocate land for agricultural and settlement purposes, while offering various forms of assistance to beneficiaries. Yet, its reliance on market-based transactions—especially the "willing buyer, willing seller"

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model—undermines its transformative potential and has failed to disrupt entrenched ownership patterns.

The Expropriation Act was introduced to give legislative effect to certain constitutional provisions. It defines lawful expropriation, offers procedural safeguards, and outlines conditions under which zero compensation may be justified—such as in cases of land held for speculation, abandoned property, or land previously acquired through state subsidies or preferential treatment [20].

These measures reflect a shift from narrowly protecting individual property rights toward a socially responsive and historically anchored conception of ownership. As the Constitutional Court held in *Haffejee and Others v eThekwini Municipality and Others* (CCT 110/10) [21], "just and equitable" compensation is not limited to market value but must reflect broader justice considerations. Expropriation thus becomes not just a legal mechanism, but a constitutional commitment to transformation.

Brazil offers a compelling case. Article 5, XXIII of its 1988 Constitution protects property, but only if it serves a social function. The National Institute for Colonisation and Agrarian Reform (INCRA) is empowered to expropriate idle or underutilised land for redistribution. Compensation is often issued via long-term government bonds, rather than cash, reinforcing the idea that redistribution does not have to follow market logic [22,23]. Though implementation has been uneven, Brazilian courts have consistently prioritised social justice over absolute property rights.

Namibia, similarly, inherited a racially skewed land ownership system. While its Constitution protects property rights, Article 16(2) permits expropriation in the public interest, with fair compensation. The Agricultural (Commercial) Land Reform Act of 1995 initially relied on a market-based model, but dissatisfaction with its slow progress led to constitutional debates and the exploration of more assertive reforms. Namibian courts have largely upheld the legitimacy of expropriation when conducted lawfully, but have insisted on procedural fairness and the right to a hearing [24].

Both cases affirm that expropriation can be compatible with constitutional architecture, so long as it serves clear public purposes. Brazil's social function doctrine offers a strong foundation for intervention, while Namibia emphasises the importance of legal clarity, institutional capacity, and careful planning.

4.2. Expropriation Without Compensation

The debate over EWC marks a pivotal moment in South Africa's democratic journey. It raises questions about rights, justice, and the redistributive obligations of the post-apartheid state.

At the centre of this debate is a clash between two paradigms: on the one hand, a liberal defence of property rights and market-led redistribution; on the other, a transformative justice framework calling for radical redress. Since 1994, South Africa's land reform programme, largely reliant on voluntary market transactions, has failed to alter the racial geography of land ownership. As Lahiff [25] observes, the "willing buyer, willing seller" model has been slow, expensive, and vulnerable to elite capture.

EWC is proposed as a remedy. It recognises that some injustices cannot be addressed through market mechanisms, and that compensating those who benefited from dispossession risks legitimising past wrongs. As Justice Dikgang Moseneke put it: "The willingness of the buyer and or of the seller may facilitate a smooth transaction but does not seem to be a constitutional requirement" [2].

Contrary to common belief, EWC is not unconstitutional. Section 25(3) allows for "just and equitable" compensation, which, in some cases, can lawfully amount to zero. This interpretation has been confirmed in both legal and academic circles [26]. The Constitution

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allows for a range of compensation outcomes, depending on context, from full market-related payment (often mischaracterised as standard "buying") to no compensation at all (often misrepresented as "confiscation").

Although a proposed constitutional amendment to Section 25 failed in 2021, the Expropriation Act provides a statutory framework through which EWC may be considered in appropriate circumstances. The Act does not establish automatic grounds for zero compensation. Rather, it affirms that compensation must remain "just and equitable" and introduces a set of factors that may be considered when determining whether compensation could be zero in a particular case. These considerations include, among others, situations where land is held for speculative purposes, where property has been abandoned, or where the acquisition or improvement of the land was substantially supported through state financial assistance or subsidies. Such provisions therefore operate within a case-by-case evaluative framework rather than as predetermined triggers for zero compensation.

Opponents argue that EWC could deter investment or destabilise property markets. Yet such arguments often rely on misleading comparisons with Zimbabwe, ignoring significant legal, institutional, and political differences between the two contexts [27].

Ethical considerations should not be eclipsed by market concerns. Section 25(3) requires that the way land was acquired be considered. As Justice Albie Sachs noted, this includes land obtained "free of charge by government or acquired at a knock-down price" under racist legal systems [2]. Hall [28,29] goes further, arguing that compensating such beneficiaries effectively rewards injustice.

At the 2025 Steve Biko Memorial Lecture, Muzi Sikhakhane issued a striking moral challenge:

"Where have you heard 65 million people from whom land was stolen saying that in order to get it back, they must litigate. . . we lived before we were invaded. . . we had laws. . . we need to create a Constitution where what was stolen must come back."

This is not to invite anarchy or disorder, but to advance constitutional transformation. EWC, when properly regulated, is not the rejection of law; it is the law fully realised in service of justice.

4.3. Economic Inclusivity

In the post-apartheid context, economic inclusivity does not just imply market participation. That could result in merely integrating the previously excluded into existing systems of inequality. Instead, it also implies redistributing systemic power and resetting the foundations of ownership and control that would enable historically marginalised communities to access and benefit from productive assets, particularly land [30].

Within African developmental thought, inclusivity is not about GDP growth alone. It means dismantling the colonial economic architecture that excludes Black people from land, finance, infrastructure, and decision-making. This requires not only policy reform but a deliberate confrontation with the inherited economic order that continues to prioritise capital over justice.

Land enables subsistence farming, cooperative enterprises, housing security, and entry into formal economies. It forms the material basis for self-reliance and collective economic agency. Without land, other interventions, such as access to finance or training, are ineffective because they are unable to take root or generate long-term transformation. Access to land is also central to food sovereignty, the informal economy, and intergenerational wealth—all of which are critical to genuine economic inclusion.

South Africa's economic structure still mirrors apartheid-era spatial and asset inequality. Productive land remains concentrated in White ownership, while Blacks remain largely landless or relegated to insecure tenure in underdeveloped areas. This spatial and asset

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divide continues to define who holds economic power and who gains from it. Piketty [31] argues that asset redistribution, especially of land, is essential in societies shaped by racial capitalism. Without it, there can be no inclusive growth.

True inclusivity requires a redistributive economic reordering. It demands a break from the logic that sees land as a mere commodity and instead centres it as a social good tied to justice, dignity, and belonging. Redistribution must therefore be seen not as an economic burden, but as a necessary investment in a more equitable and stable society. EWC—particularly where compensation would entrench past injustice—must be seen as a prerequisite for sustainable, broad-based development. Without it, democracy risks being layered over economic apartheid, preserving the illusion of transformation while leaving the foundations of dispossession intact.

4.4. Social Equity

Social equity goes beyond the idea of treating everyone the same. It demands contextual justice, an approach that recognises the need for differentiated responses to historical and systemic inequality. In the South African context, this means recognising that those who were dispossessed, displaced, and marginalised under colonialism, segregation and apartheid require targeted remedies to achieve substantive parity with those who benefited from these systems [32]. In a society where land was a central mechanism of exclusion, restoring it is not just a matter of policy reform, but of democratic fulfilment.

Equality, in its formal sense, assumes that all citizens start from the same place. But equity acknowledges that the starting points have been wholly unequal, and that the playing field itself has been engineered to privilege some at the expense of others. EWC offers a direct response to this reality. It does not undermine the principle of equality. It reinforces it, by addressing the legacy of land dispossession and the racialised economic structures that remain in place. The aim is not revenge, but justice: to deal honestly with unequal histories by applying remedies that reflect their depth and impact.

Section 9 of the Constitution enshrines the right to equality, including equity, which allows for the state to take positive measures to redress disadvantage. Importantly, it is not limited to non-discrimination; it requires proactive intervention. EWC, when undertaken in accordance with the law and the Constitution, is not an aberration. It is a constitutionally permissible, even necessary, instrument to correct enduring patterns of injustice.

Moreover, social equity is not just a moral ideal or political talking point; it is a legal duty, firmly enshrined in the Constitution and central to its transformative vision for a just society. It ties South Africa's history of injustice to the promises of its democracy, urging the state to go beyond token measures and commit to material redress. Land, as a foundational asset, lies at the heart of this redress.

The pursuit of equity must also be accompanied by vigilance: policies like EWC must be implemented transparently, lawfully, and with clear criteria to avoid abuse, elite capture, or further exclusion. But the existence of risks does not negate the moral and constitutional necessity of the intervention.

In short, equity is not about forgetting the past—it is about facing it honestly. It is not about erasing history, but about confronting it and addressing its consequences. Unless the lasting effects of land dispossession are properly addressed, South Africa's democracy will remain incomplete, offering formal rights while leaving opportunity out of reach for many.

4.5. Spatial Justice

Spatial justice refers to the fair distribution of land, infrastructure, and opportunity across space. In South Africa, inequality is not only racial or economic; it is also pro-

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foundly spatial, produced through centuries of forced removals, segregated planning, and legalised exclusion.

SPLUMA mandates spatial justice as a core planning principle, with Section 7(a) calling for the redress of past imbalances and improved access to land for disadvantaged communities. Yet, despite this clear legislative intent, implementation remains inconsistent and often falls short of meaningful transformation.

Restorative spatial transformation must actively reconfigure unjust geographies. This includes reintegrating displaced communities into well-located areas, unlocking strategically situated urban land for affordable housing, and dismantling the persistent divide between townships and urban cores. It is not only about preventing future exclusion; it is about actively reversing the spatial patterns of injustice that continue to shape daily life.

The Constitutional Court has started to give shape to this principle. In landmark decisions such as *Residents of Joe Slovo Community, Western Cape v Thubelisha Homes and Others* (CCT 22/08) [33] and *Occupiers of 51 Olivia Road v City of Johannesburg* (CCT 24/07) [34], the Court affirmed that decisions about land use and housing must centre the values of dignity, participation, and inclusion. These rulings signal a growing recognition that spatial redress is fundamental to the constitutional promise of justice and equality.

Spatial justice is also inherently multidimensional. It demands an awareness of how spatial exclusion intersects with other forms of marginalisation. Women's access to land, for instance, remains limited by both formal legal barriers and customary norms that reinforce patriarchy. Similarly, people with disabilities and migrants often face added layers of exclusion in the design and allocation of space and services.

Ultimately, spatial justice calls for a rethinking of land reform as a process of reconstruction. It insists that justice must be built into the very layout of our cities, towns, and rural landscapes—making space itself a site where justice is not only envisioned but actively realised.

4.6. The Pan-African City

The concept of the Pan-African City, as developed in this study, refers to a decolonised and spatially just urban formation grounded in principles of collective ownership, dignity, belonging, and democratic access to land. It is not presented as an established statutory model or formal planning doctrine, but as a normative and analytical construct derived from Pan-African political thought and African urban scholarship. Its intellectual foundations lie in traditions that emphasise self-determination, post-colonial sovereignty, and the reclamation of African space from colonial and apartheid spatial orders.

African urban theorists such as Simone, Nuttall and Mbembe [35,36] have argued that African cities cannot be understood through imported Eurocentric planning paradigms alone. Instead, they must be analysed through their own histories of informality, hybridity, and spatial contestation. Similarly, Soja's articulation [37] of spatial justice and Lefebvre's "right to the city" tradition (as extended in African scholarship) emphasise that urban space is not neutral but politically produced. The Pan-African City concept engages these debates by foregrounding the question of land ownership as the central axis of urban transformation.

In the South African context, cities remain structured by colonial conquest and apartheid engineering. Despite formal desegregation, well-located urban land continues to be concentrated in private hands, often subject to speculative holding and exclusionary market practices. The Pan-African City is therefore not just symbolic; it represents a structural reordering of urban land relations. It envisions cities in which land is treated as a social good rather than a speculative commodity, and where historically marginalised communities are not only accommodated but empowered as co-producers of urban space.

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The concept serves a specific analytical purpose in this paper: it connects land expropriation—including EWC in constitutionally justified circumstances—to a broader project of spatial reconstruction. Rather than treating land reform as a rural or agrarian question alone, the Pan-African City reframes it as an urban justice imperative. Expropriation of underutilised, speculative, or strategically located urban land becomes a mechanism through which constitutional commitments to dignity (Section 10), equality (Section 9), equitable access to land (Section 25), and housing (Section 26) can be materially realised.

The Pan-African City should thus be understood as a forward-looking normative horizon—a conceptual device that integrates economic inclusivity, social equity, and spatial justice into a coherent urban vision. It does not replace existing planning frameworks but challenges them to confront the enduring coloniality embedded in property relations and spatial form. In this sense, it situates land reform within a broader continental and decolonial discourse on reclaiming African cities for the majority who inhabit them.

5. Housing, Urban Inclusion, and the Pan-African City

While land reform in South Africa is often framed as a rural issue, its most urgent implications are now distinctly urban. The majority of South Africans live in cities, yet access to well-located urban land remains acutely unequal. This inequality is shaped not only by apartheid-era planning legacies but also by speculative markets and exclusionary zoning practices. The persistence of informality, insecure tenure, evictions, and the peripheralisation of the poor exposes the failure to treat land justice as central to urban inclusion. This critical blind spot in post-apartheid land reform led SERI [38] to observe that current policy largely leaves unchallenged the combined influence of market forces and inherited spatial forms in perpetuating exclusionary urban landscapes.

5.1. Urban Informality and the Politics of Land Access

While colonial and apartheid spatial planning established the structural foundations of South Africa's urban form, contemporary market-based and technocratic planning mechanisms operate as the primary processes through which these historical spatial inequalities continue to be reproduced. Informality in South African cities is not an anomaly but a direct result of ongoing exclusion. It shows up in the way people are forced to live: in informal settlements, backyard shacks, and overcrowded homes, often without secure tenure or basic services. This condition stems from a legal and policy framework that treats urban land primarily as something that individuals and corporates buy and sell instead of something held in the public interest [13].

The absence of proactive urban land reform has enabled speculative forces to dominate, placing well-located land beyond the reach of poor and working-class communities. The bigger housing developments, regularly positioned on the urban edge reflect a technocratic model that prioritises scale and efficiency over integration and equity. While not mirroring apartheid design by intent, these megaprojects often entrench new forms of marginalisation under the aegis of development.

Instead of regularising informality or integrating marginalised communities, urban planning regimes frequently criminalise land occupations and enforce evictions, thereby sustaining a system where urban presence is tolerated but not recognised in law or policy. Though these practices may echo apartheid-era exclusions, today's drivers are primarily market-based and technocratic, not racially prescriptive. As COHRE [39] observed regarding Johannesburg's inner-city evictions, these approaches marginalise the urban poor, often under the guise of urban renewal. Urban land, therefore, must be reframed as a constitutional right and redistributive necessity, not just a planning concern.

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5.2. Spatial Justice in the African City

Across Africa, urban development is characterised by deep inequalities and fragmented spatial realities. Informal settlements often exist alongside elite enclaves, shaped by a post-colonial urbanism that perpetuates marginalisation through exclusionary planning and market-led growth. In South Africa, the spatial legacy of segregation persists, not through deliberate replication, but through the obduracy of inherited urban forms and the continued primacy of technocratic planning.

Access to land, infrastructure, and opportunity in South Africa still follows the patterns of historical exclusion. Today, that exclusion continues through tools that appear neutral on the surface, such as zoning laws, decisions about where infrastructure is built, and the way land markets operate. The Constitution, through Sections 25(5) and 26, clearly recognises the rights to fair access to land and decent housing. But in practice, these rights are limited by a development model that puts the value of land as an investment ahead of the need for fundamental social change.

If South Africa is serious about spatial justice, then simply handing out land or improving basic services is not enough. What is needed is a complete rethinking of the city as a space that includes everyone. As Soja [37] reminds us, spatial justice is tied to the idea of the "right to the city"—the right to help shape urban life and be part of it. That means facing up to how land works in today's economy and moving past the trope of "apartheid geography" explaining everything. Real justice now depends on building new ways of thinking about space, ones that centre collective ownership, serve the public good, and open access to land in ways that are truly democratic.

5.3. Land Reform as a Catalyst for Inclusive Urban Development

To fulfil its constitutional assurances, land reform must be placed at the heart of urban transformation. This entails not just redistribution, but a fundamental rethinking of planning and governance. A transformative urban land reform agenda would include:

- Expropriation of well-located, underutilised urban land for public benefit;
- Strengthening tenure security in informal settlements through participatory upgrading and alternative legal instruments (e.g., collective titling, usufruct rights);
- Implementing land value capture mechanisms to redirect speculative gains toward public investment;
- Integrating housing, land, and infrastructure planning through a justice-based lens;
- Enabling community-driven planning that empowers residents as co-producers of urban space.

Realising this vision means breaking away from the usual ways cities are planned, especially the tendency to see informality as something that needs to be wiped out. It also calls for a more assertive state, one that is willing to use the tools offered by the Constitution, including EWC, to disrupt the deeply rooted patterns of exclusion that still shape urban life.

5.4. Afrocentric Urbanism and Land Justice

The Pan-African City offers a template for a desirable post-colonial urban future. It is not a theoretical ideal but a practical blueprint for cities founded on principles of land justice, Afrocentric design, democratic governance, and ecological sustainability.

A Pan-African City is:

- Decolonial in design: It rejects grid plans and exclusionary zoning for people-centred spatial arrangements;
- Collective in land ownership: It recognises land as a common good and promotes communal tenure;

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- Plural in identity: It values diverse cultural practices of space-making;
- Redistributive in economics: It uses land reform to broaden access to infrastructure, livelihood, and dignity.

Seen this way, land reform is about more than just fixing rural injustices. It is also a way to take back urban space from planning systems shaped by colonial ideas and from the grip of the market. The idea of a Pan-African City reflects this, as it gives physical form to justice and equity through new ways of imagining and shaping our cities.

5.5. Economic Inclusivity, Social Equity, Spatial Justice and the South African City

For economic inclusion, social justice, and spatial justice to be fully realised, the urban aspects of the land crisis must be tackled decisively. This will require more than policy changes; it necessitates a shift in how the city is conceived—not as a space for control or containment, but as a site of transformation. Land EWC, when grounded in constitutional and moral legitimacy, should be understood as essential to achieving justice in cities, not only in rural areas. Without meaningful change in how urban space is owned and shared, the promises of post-apartheid democracy will remain out of reach.

6. Critique of Post-Apartheid Land Reform Policy

Democratic transition came with a constitutional commitment that land reform would be a tool for redress, equity, and transformation. However, more than three decades later, land reform remains one of South Africa's most unfulfilled promises. The policy path since 1994 shows a clear tension between justice and market logic, alongside a failure to disrupt the deep-rooted structures of racialised land ownership. This section looks critically at how land reform policy has developed over time, from the first-generation reforms of the 1990s and early 2000s to the second-generation reforms introduced after 2010, which focused more on integration and spatial justice.

6.1. First-Generation Land Reform: Restitution, Redistribution, and Tenure Reform

Underpinned by a cautious embrace of constitutionalism and the rule of law, the land reform programme was initially organised around a tripartite framework: restitution, redistribution, and tenure reform. While symbolically significant, this framework ultimately came to reflect a dispassionate, even callous, compromise: it prioritised legal continuity and market stability over radical transformation [18,40].

The Restitution of Land Rights Act of 1994 [41] sought to restore land or afford alternative compensation to individuals or communities dispossessed after 19 June 1913, under racially discriminatory laws and practices. However, the restitution process has been protracted, underfunded, and heavily legalistic, with an over-reliance on litigation and insufficient support for post-settlement development [9]. Although, by 31 March 2024, restitution claims had reportedly resulted in the return of about 3.9 million hectares of land, the majority of the 83,205 successful land claims have been settled through cash compensation amounting to R26 billion—effectively re-inscribing dispossession rather than reversing it [42].

From its inception, the redistribution programme, intended to equitably transfer agricultural land, has adopted a demand-led approach through the "willing buyer, willing seller" model. Predicated on a market-friendly interpretation of the Constitution, this mechanism has relied on voluntary transactions, state subsidies, and negotiated purchases. However, this model continues to prove inefficient, expensive, and poorly targeted, often enabling the acquisition of marginal or non-viable land, while failing to disrupt concentrated patterns of ownership [25]. Its failure to redistribute land at scale points not only

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to technical limitations, but to the ideological refusal to challenge private property as a structural barrier.

The third pillar—tenure reform—has perhaps been the most neglected. Aimed at securing the rights of communal land occupiers, labour tenants, farm dwellers, and others with informal or off-register rights, this programme has been encountering serious political and legal complexity, particularly in former Bantustans. Customary land governance, intersecting with patriarchy, elite appropriation, and state abdication, has produced a tenure regime characterised by legal ambiguity, gender discrimination, and community disempowerment [12]. The Communal Land Rights Act of 2004 [43], expected to clarify rights in these areas, was declared unconstitutional in 2010 for failing to uphold participatory and democratic governance of land (*Tongoane & Others v Minister of Agriculture and Land Affairs and Others*, CCT 100/09) [44].

These first-generation reforms, while legally significant, remain trapped within the logic of reconciliation without redistribution. They offer procedural justice without structural change, ultimately leaving the racialised land patterns they were meant to undo, largely intact.

6.2. Second-Generation Land Reform: SPLUMA, IDPs, and Housing Strategies

By the early 2010s, it became increasingly clear that land reform could not be addressed in isolation from spatial planning, urbanisation, and integrated development. The state's response was a second generation of additional policy tools aimed at aligning land use, human settlement, and socio-economic planning within a unified developmental framework.

SPLUMA was introduced to replace the fragmented and racially biased planning laws left behind by apartheid. It set out to build a single, coherent system for managing land use across all levels of government. Its goals included promoting sustainable development and aligning spatial planning with constitutional values like equality and redress [45].

But while SPLUMA had progressive aims, its real-world impact has been limited. The main reasons include patchy implementation, weak coordination between institutions, and a failure to connect land use planning with the goals of land reform. Municipalities, which are supposed to lead implementation, often lack the resources or political backing to bring land reform into their spatial plans. On top of that, SPLUMA does not fit well with customary or communal land systems. This mismatch creates confusion over who has authority and often leads to the exclusion of rural communities [46].

At the same time, tools like Integrated Development Plans (IDPs) and the National Housing Code were introduced to support more inclusive urban development by improving access to housing, services, and jobs. The *Breaking New Ground: A Comprehensive Plan for the Development of Sustainable Human Settlements* policy was introduced in 2004 as a major shift in South Africa's housing policy framework, moving beyond the earlier Reconstruction and Development Programme (RDP) housing approach toward the development of integrated and sustainable human settlements. Subsequent policy developments after 2014 did not introduce BNG as a new programme but rather reflected renewed policy emphasis, institutional recalibration, and implementation adjustments within the broader BNG framework [47]. Post-2014 developments, therefore, represent policy refinement and renewed implementation efforts within the BNG framework rather than the initial introduction of the policy.

Even so, these efforts have largely remained disconnected from land reform, both in how they are understood and how they are carried out. Many housing projects go ahead without dealing with the underlying land ownership issues. This often results in insecure tenure, growing informal settlements, and the takeover of well-located land by elites. The issue of urban land, which plays a major role in sustaining inequality, has not been properly

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addressed in spatial planning. In many cases, the state continues to operate more like a developer than a force for redistribution [13].

6.3. Policy Failure, Bureaucratic Paralysis, and the Urban-Rural Divide

Despite the avowed commitment to transformation, land reform in South Africa has struggled to move forward. It has been held back by acute systemic lethargy, unclear legal arrangements, and political avoidance. The state's approach has often leaned toward technocratic solutions, prioritising compliance and process over real outcomes and a sense of justice.

There are several key weaknesses that continue to limit progress:

- Lack of political will: Land reform has been subordinated to the goals of macroeconomic stability and elite consensus. As a result, there has been little disruption to entrenched agrarian and urban interests.
- Bureaucratic delays: Confusion over mandates, chronic underfunding, and sluggish administration have stalled institutions meant to deliver land reform. This has created serious backlogs and eroded public confidence in the process.
- Policy incoherence: There has been a failure to align land reform with related areas like urban planning, housing, and local government. This has led to a fragmented response and has reinforced the urban-rural binary. Land reform is still largely treated as a rural issue, even as cities grow rapidly and informal settlements expand.

Collectively, this policy review shows that post-apartheid land reform has fallen short of being the transformative agenda it was meant to be. It has instead functioned as a managed transition, designed to protect existing property relations while offering negligible redress to the landless. Without a decisive shift in legal interpretation, political will, and state capacity, even the most well-intentioned reforms will continue to reproduce containment rather than enable transformation.

7. The Litmus Test for EWC

In 2019, the City of Ekurhuleni in Gauteng Province expropriated a 34-hectare property—Portion 406 of the Driefontein Farm—owned by Business Venture Investments 900. The municipality offered zero compensation, contending that the land had remained vacant for approximately three decades, had been held purely for speculative purposes, contained no improvements or lease agreements, and that the public interest—particularly the development of social housing to relieve pressure from nearby informal settlements—outweighed the private owner's proprietary interests. Although the owner did not contest the legality of the expropriation itself, it disputed the amount of compensation, asserting entitlement to at least R30 million. An independent valuation had placed the property's market value at approximately R64 million.

The dispute consequently became the subject of mediation proceedings scheduled for October 2025. Those negotiations ultimately failed to produce a settlement, and the matter was set down for trial in February 2026. The case attracted significant public and scholarly attention because it was widely expected to serve as an important judicial test of Section 25 of the Constitution, particularly regarding the circumstances under which compensation for expropriated land might lawfully be set at zero [48,49]. However, shortly before the scheduled trial, the municipality reversed its position. In January 2026, following the completion of an environmental assessment, the City withdrew its intention to acquire the property on the basis that the land was unsuitable for human settlement. As a result, the anticipated judicial determination did not materialise.

Nevertheless, the dispute remains analytically significant. Even in the absence of a final court ruling, the factual circumstances and legal arguments advanced by the parties

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provide a useful basis for considering the kinds of factors that courts might weigh when assessing the constitutionality and justification of zero compensation under Section 25. In this sense, the case still permits a degree of anticipatory analysis regarding the possible contours of future jurisprudence on land EWC in South Africa.

Commenting on the Driefontein Farm case, former South African Property Owners Association (SAPOA) Chairperson Neil Gopal said: "A buy-and-hold strategy is an internationally recognised real estate approach. If you expropriate property held under such a strategy for zero compensation, it will disrupt property market fundamentals, as well as capital flows and capital markets" [48].

But that disruption is precisely the point. The very fact that it unsettles property markets is why it must happen. The current property market logic was never neutral. It is structured to reward exclusion and inequality. It was deliberately designed to entrench historical inequality by commodifying land and concentrating it in the hands of a few, often for speculative gain rather than productive use.

This market structure rewards hoarding over utilisation: land is bought not to meet basic needs or drive development, but to appreciate passively while others remain landless. As a result, vast tracts of urban and rural land sit idle while millions live without secure tenure or adequate housing. The cycle must be broken. Disrupting this perverse incentive structure is not a threat to the public interest—it is a precondition for a just and sustainable property system.

The South African Constitution is not silent on the friction between individual property rights and the public good. Section 25 explicitly permits the expropriation "in the public interest," which includes "the nation's commitment to land reform." Moreover, the Constitution recognises that collective rights—such as equitable access to land, dignity, and socio-economic security—may override individual property claims when those claims perpetuate structural injustice.

Where land is being withheld from productive use purely to accumulate value, particularly in a context of deep historical dispossession, the individual's right to monopolise cannot supersede society's collective right to redress, equitable distribution, and social justice. Compounding this is the fact that Gauteng is by far the smallest province in terms of land area, yet the most densely populated, with a steadily growing influx of households from other provinces and outside the country contributing to an ever-worsening housing backlog and land shortage.

Far from encouraging healthy investment, land speculation distorts the economy. It pushes land prices well beyond their real value, pulls money away from sectors that produce goods and jobs, and locks land out of circulation for years, sometimes even decades. This kind of extractive behaviour creates artificial scarcity, deepens spatial inequality, and holds back inclusive growth.

If South Africa were to expropriate speculative, buy-and-hold land without compensation, it would not only bring land use policy in line with the Constitution's transformative vision—it would also unlock economic potential that has been sitting idle. This move would support social justice and directly tackle the legacy of dispossession that sits at the heart of inequality. Taking back such land would not destabilise the economy. On the contrary, it would help reset the property market so that it serves its real purpose of meeting people's needs, supporting development, and helping build a fairer economy. By putting unused land to work, the state could boost local economies, create jobs, and open the door for more investment in infrastructure and enterprise.

South Africa's property system is not just an economic arrangement. It is ingrained in the history of colonialism, segregation, and apartheid. These systems stripped land and wealth from the Black majority and handed ownership to a minority. That ownership was

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later locked in and valorised through market mechanisms that continue to shape property relations today.

Allowing speculative buy-and-hold practices to continue is not only a policy failure; it perpetuates historical injustice under the guise of "market efficiency." Real reconciliation and meaningful transformation require more than redistributing land—they demand dismantling the systems that entrench inequality. EWC, carefully targeted at land not being used for productive or public purposes, is a necessary tool in that process. It is important to be clear: this argument is not about indiscriminate seizure. It is about making deliberate, strategic choices. Specifically, it requires expropriating land, that is:

- Held only for speculative gain, with no productive use or social value;
- Blocking land reform, housing, or economic development;
- Driving artificial scarcity and pushing up land prices.

In these cases, EWC is not a punishment; it is a correction. It recalibrates the relationship between private property and the public good, ensuring that property serves society and not the other way around.

8. Conclusions

This paper has argued that land expropriation, particularly without compensation, is not only a necessary response to historical dispossession, but also a vital step toward building economic inclusion, social equity, and spatial justice in post-apartheid South Africa. Anchored in a constitutional framework that prioritises redress, dignity, and transformation, land reform must be seen as both a legal obligation and a moral necessity.

For centuries, colonial conquest and apartheid policies forcibly removed Black people from land and cities, creating a geography of exclusion that still shapes the country's economic and social realities. Although post-apartheid land reform has carried notable weight, it has fallen short of driving meaningful structural change. This failure is largely due to market-driven approaches, bureaucratic delays, and a lack of political commitment. As a result, millions of people remain marginalised, especially in urban areas where informal settlements and insecure land tenure continue to reflect the neglected work of liberation.

This paper has shown that land must be understood as more than just a commodity. It is also a source of livelihood, identity, and belonging. When viewed this way, land reform becomes closely tied to broader development goals such as reducing poverty, achieving food security, creating more inclusive cities, and transforming spatial patterns of inequality. Whether through restitution or planning instruments like SPLUMA, expanding land access must be directly linked to economic opportunity and the full experience of citizenship.

One of the conceptual contributions of this paper has been to connect land reform with the normative construct of the Pan-African City, thereby situating debates on expropriation within broader discussions of decolonial urban transformation and spatial justice. This shifts the conversation away from land reform as a technical or bureaucratic process, and toward a deeper transformation of how cities in Africa are conceived and built.

To move forward, South Africa needs a bold and programmatic approach to land expropriation. This strategy must be rooted in the law, guided by ethical principles, and carried out with political courage. It will require new, third-generation policy tools. These include fully using Section 25 of the Constitution, implementing expropriation legislation, and connecting land reform to housing, planning, and development in a much more integrated way. It also means rejecting narratives driven by fear and making it clear that restitution is not about retribution—it is about restoring land, dignity, and the democratic vision that inspired the struggle for freedom.

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In the end, land expropriation is not just about correcting the past. It is about building a just future. The path to economic inclusion, social equity, and spatial justice runs through the land. Until land is fairly shared, the work of liberation remains unfinished.

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Note

[1] Legislatively, "Black people" includes Africans, Coloureds, Indians and, in certain specific contexts, also Chinese. While these sub-groups were often subjected to disparate legal treatment throughout the pre-democratic period, a detailed examination of this important issue falls outside the scope of this paper.

References

1. Republic of South Africa. *Constitution of the Republic of South Africa*; Government Printer: Pretoria, South Africa, 1996.
2. Republic of South Africa. *Final Report of the Presidential Advisory Panel on Land Reform and Agriculture*; Government Printer: Pretoria, South Africa, 2019.
3. Cousins, B. *Land Reform in South Africa Is Sinking. Can It be Saved?* Nelson Mandela Foundation: Johannesburg, South Africa, 2020.
4. DALRRD. *Land Audit Report*; Department of Agriculture, Land Reform and Rural Development: Cape Town, South Africa, 2021.
5. Republic of South Africa. *Report of the High Level Panel on the Assessment of Key Legislation and the Acceleration of Fundamental Change*; Government Printer: Pretoria, South Africa, 2017.
6. Ariyan, L. *Living Worlds Apart—In the Same Country!* Sanbun: New Delhi, India, 2008.
7. Plaatje, S. *Native Life in South Africa*; Ravan Press: Johannesburg, South Africa, 1982.
8. Bundy, C. Centenary of the 1913 Land Act By Colin Bundy, 18 April 2013. *Africa History Online*, 19 June 2013. Available online: https://sahistory.org.za/archive/centenary-1913-land-act-colin-bundy-18-april-2013 (accessed on 23 March 2026).
9. Walker, C. *Landmarked: Land Claims and Land Restitution in South Africa*; Jacana Media: Johannesburg, South Africa, 2008.
10. Ariyan, L. *Foreigners in the Land of their Birth*; Sanbun: New Delhi, India, 2006.
11. Walker, C. *A Common Hunger: Land Rights in Canada and South Africa*; University of Calgary Press: Calgary, AB, Canada, 2008.
12. Claassens, A.; Cousins, B. (Eds.) *Land, Power and Custom: Controversies Generated by South Africa's Communal Land Rights Act*; UCT Press: Cape Town, South Africa, 2008.
13. Huchzermeyer, M. *Cities with 'Slums': From Informal Settlement Eradication to a Right to the City in Africa*; UCT Press: Cape Town, South Africa, 2011.
14. Turok, I. South Africa's New Urban Agenda: Transformation or Compensation? *Local Econ.* **2016**, *31*, 9–27. [CrossRef]
15. Ntsebeza, L.; Hall, R. (Eds.) *The Land Question in South Africa: The Challenge of Transformation and Redistribution*; HSRC Press: Cape Town, South Africa, 2007.
16. Fraser, A. Land Reform in South Africa and the Colonial Present. *Soc. Cult. Geogr.* **2007**, *8*, 835–851. [CrossRef]
17. Klare, K. Legal Culture and Transformative Constitutionalism. *S. Afr. J. Hum. Rights* **1998**, *14*, 146–188. [CrossRef]
18. Lahiff, E. *Land Reform in South Africa: A Status Report 2008*; PLAAS Research Report No. 38; University of Western Cape: Western Cape, South Africa, 2008.
19. Republic of South Africa. *Provision of Land and Assistance Amendment Act*; Act No. 58 of 2008; Government Printer: Pretoria, South Africa, 2008.
20. Republic of South Africa. *Expropriation Act*; Act No. 13 of 2024; Government Printer: Pretoria, South Africa, 2024.
21. Constitutional Court of South Africa. CCT 110/10. Haffejee and Others v EThekwini Municipality and Others. Available online: https://collections.concourt.org.za/handle/20.500.12144/3636 (accessed on 23 March 2026).
22. Deininger, K.W. Making Negotiated Land Reform Work: Initial Experience from Colombia, Brazil and South Africa. *World Dev.* **1999**, *27*, 651–672. [CrossRef]

https://doi.org/10.3390/land15040573

23. Emanuelli, M.S.; Rivas, R.G. The Social Function of Land Ownership: Social Claims and Legal Decisions in rural Brazil. In *Take Back the Land! The Social Function of Land and Housing, Resistance and Alternatives*; Mathivet, C., Ed.; Ritimo: Paris, France, 2014.
24. Harring, S.L.; Odendaal, W. *No Resettlement Available: An Assessment of the Expropriation Principle and Its Impact on Land Reform in Namibia*; Legal Assistance Centre: Hong Kong, China, 2007.
25. Lahiff, E. 'Willing buyer, willing seller': South Africa's failed experiment in market-led agrarian reform. *Third World Q.* **2007**, *28*, 1577–1598. [CrossRef]
26. Lubbe, H.; du Plessis, E.W.J. Compensation for Expropriation in South Africa, and International Law: The Leeway and the Limits. *Const. Court. Rev.* **2021**, *11*, 79–112. [CrossRef]
27. Oduro-Marfo, S. Land Expropriation Without Compensation: Is It a Threat to South African Constitutionalism? *University of Victoria Online*, 23 October 2018. Available online: https://onlineacademiccommunity.uvic.ca/globalsouthpolitics/2018/10/23/land-expropriation-without-compensation-is-it-a-threat-to-south-african-constitutionalism/ (accessed on 23 March 2026).
28. Hall, R. *Compensating for Stolen Land Is Not Justice; It Is Rewarding Dispossession*; PLAAS Blog: Western Cape, South Africa, 2018.
29. PLAAS. *Equitable Access to Land for Social Justice*; PLAAS: Cape Town, South Africa, 2021.
30. Adésinà, J.O. Social policy in sub-Saharan Africa: A glance in the rear-view mirror. *Int. J. Soc. Welf.* **2009**, *18*, S37–S51. [CrossRef]
31. Piketty, T. *A Brief History of Equality*; English Translation of Une brève histoire de l'égalité, 2021; Harvard University Press: Cambridge, MA, USA, 2022.
32. Sen, A. *Development as Freedom*; Oxford University Press: Oxford, UK, 1999.
33. Constitutional Court of South Africa. CCT 22/08. Residents of Joe Slovo Community, Western Cape v Thubelisha Homes and Others. Available online: https://collections.concourt.org.za/handle/20.500.12144/34560 (accessed on 23 March 2026).
34. Constitutional Court of South Africa. CCT 24/07. Occupiers of 51 Olivia Road, Berea Township and 197 Main Street, Johannesburg v City of Johannesburg and Others. Available online: https://collections.concourt.org.za/handle/20.500.12144/3316 (accessed on 23 March 2026).
35. Nuttall, S.; Mbembe, A. (Eds.) *The Elusive Metropolis*; Duke University Press: Durham, NC, USA, 2005.
36. Simone, A. *For the City Yet to Come: Changing African Life in Four Cities*; Duke University Press: Durham, NC, USA, 2004.
37. Soja, E.W. *Seeking Spatial Justice*; University of Minnesota Press: Minneapolis, MN, USA, 2010.
38. SERI. *Edged Out: Spatial Mismatch and Spatial Justice in South Africa's Main Urban Centres*; Socio-Economic Rights Institute Online Land Portal: Johannesburg, South Africa, 2016.
39. COHRE. *Any Room for the Poor? Forced Evictions in Johannesburg, South Africa*; Centre on Housing Rights and Evictions: Geneva, Switzerland, 2005.
40. Hall, R. A Political Economy of Land Reform in South Africa. *Rev. Afr. Political Econ.* **2004**, *31*, 213–227. [CrossRef]
41. Republic of South Africa. *Restitution of Land Rights Act*; Act No. 22 of 1994; Government Printer: Pretoria, South Africa, 1994.
42. DRDLR. *"Agriculture, Land Reform and Rural Development on Resolution of Land Claims" An Update by the Department of Rural Development and Land Reform*; DRDLR: Pretoria, South Africa, 2024.
43. Republic of South Africa. *Communal Land Rights Act—Since Declared Unconstitutional*; Act No. 11 of 2004; Government Printer: Pretoria, South Africa, 2004.
44. Constitutional Court of South Africa. CCT 100/09. Tongoane and Others v National Minister for Agriculture and Land Affairs and Others. Available online: https://collections.concourt.org.za/handle/20.500.12144/3597 (accessed on 23 March 2026).
45. Republic of South Africa. *Spatial Planning and Land Use Management Act*; Act No. 16 of 2013; Government Printer: Pretoria, South Africa, 2013.
46. Poswa, X. *Land Use Management: Where Traditional and Municipal Governance Meet in Rural Areas*; Local Government Bulletin: Hong Kong, China, 2019; Volume 14.
47. Department of Housing. *Breaking New Ground: A Comprehensive Plan for the Development of Sustainable Human Settlements*; Department of Housing, Republic of South Africa: Pretoria, South Africa, 2004.
48. Moneyweb. Available online: www.moneyweb.co.za (accessed on 26 September 2025).
49. The Citizen. Ekurhuleni Explains Why It Won't Compensate Owner After Expropriating R30m Land—Report. 21 September 2025. Available online: https://www.citizen.co.za/news/ekurhuleni-explains-why-wont-compensate-owner-land-expropriation/ (accessed on 23 March 2026).

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Review

Ideological Enlightenment and Practices of Sustainable Afforestation and Urban Greening: Historical Insights from Modern Guangdong, China

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Abstract: The rapid industrialization and urbanization of the modern era caused widespread deforestation and ecological degradation, raising global concerns about sustainable planning, urban green space, and environmental governance. Around the turn of the 20th century, Guangdong Province in China suffered severe environmental decline due to extensive deforestation, threatening public health, ecological resilience, and urban livability. In response, returning Chinese intellectuals and foreign forestry experts introduced advanced Western forestry theories and practices to address these crises and promote green urban development. This study examines how these transnational forestry ideas were ideologically embraced, locally adapted, and institutionally embedded in modern Guangdong's afforestation and urban greening efforts. Drawing on a systematic review of historical literature, forestry journals, and government archives, it identifies three key developments. (1) In ideology, figures such as Yat-sen Sun and German forester Fenzel played vital roles in raising public awareness of afforestation. (2) In practice, Guangdong developed a diversified greening model integrating commemorative, ecological, and aesthetic functions. This included transforming Arbor Day into a civic ritual honoring Yat-sen Sun, establishing nurseries and forest farms for large-scale afforestation, systematically planting street trees in urban centers, and creating forest parks that combined conservation, recreation, and historical commemoration. (3) In regulation, Guangdong formulated forestry laws inspired by Western models. By this way, Guangdong effectively addressed the management challenges in urban greening practices. It should also be emphasized that these modern-era practices have persisted in Guangdong, and their historical experience provides a valuable reference for present-day urban greening. Additionally, Fenzel's methods for planning nurseries and forest farms can be seen as early prototypes of "evidence-based planning". By highlighting a historically grounded yet under-explored case, this research offers new insights into the long-term evolution of urban greening strategies and provides lessons for current global efforts in sustainable land use and resilient urban design.

Keywords: sustainable planning; urban green space; afforestation; urban greening; western forestry knowledge; modern Guangdong

1. Introduction

In the context of modern history, the rapid advancement of industrialization and urbanization has led many countries to face issues such as forest resource depletion and en-

vironmental degradation [1]. To address these pressing issues, Western countries pioneered the development of afforestation knowledge and technologies, which extended beyond large-scale reforestation efforts to include urban greening practices aimed at enhancing urban green spaces and promoting ecological sustainability. These experiences provide valuable references for the sustainable planning and development of afforestation and urban green spaces in modern China and other regions worldwide [2].

In the late 19th and early 20th centuries, Guangdong, as a vital gateway for the introduction of Western ideas, experienced a severe period of forest degradation. The deterioration of its natural environment posed significant threats to public well-being and the sustainable development of its urban landscapes. Recognizing the crucial role of urban green space in sustainable city planning, a group of returning Chinese and foreign scholars introduced advanced Western concepts of afforestation and urban greening during the late Qing dynasty and early Republican periods. Notably, influenced by the U.S. municipal system, Guangzhou became the first Chinese city to establish a formal city hall in 1921 [3]. During this era, municipal construction was widely seen as a primary vehicle for national revitalization in the West, with afforestation playing an integral role in creating resilient and livable urban environments. Within this framework, Guangdong—centered on Guangzhou—actively integrated afforestation and urban greening into its municipal development plans, positioning these green initiatives as key strategies for promoting sustainable urban modernization and enhancing urban vibrancy. This historical process highlights that Western afforestation thought influenced not only forestry development but also the broader sustainable planning and resilience-building of Guangdong's urban environments.

However, despite its importance, this chapter in history has received relatively limited attention from scholars. A limited number of studies have touched on related topics. Chen [4] analyzed the legal framework of modern forestry in Guangdong. Chen [5] investigated ecological disaster prevention related to forest degradation in the Hanjiang River Basin from the Qing Dynasty to the Republican era. Marks [6] and Saito [7] studied the Lingnan region with Guangdong as the focus. Saito contrasted Lingnan with Japan, examining population growth's impact on forest cover, while Marks briefly noted that Lingnan's 18th–19th century forest planting patterns were influenced by Sino–Western trade but did not elaborate further. From a broader perspective of urban planning and sustainable development, Xu [8] reviewed the century-long history of public green space development in modern Guangzhou, including street greening and the evolution of sidewalks and street trees, highlighting the significance of public green spaces for urban planning and sustainability in Guangzhou. Han [9] examined how municipal planning in Guangzhou facilitated urban expansion, road construction, and land management, interpreting the specific content of urban greening work carried out in modern Guangzhou based on programmatic documents such as the Guangzhou Municipal Government Administration Plan and the Outline Draft of Guangzhou Urban Design. Similarly, Zou [10] analyzed these foundational documents, noting that the urban greening measures they proposed not only advanced the modernization of Guangzhou's urban planning but also served as a reference for greening initiatives in other cities.

While these studies contribute to understanding the history of afforestation and urban greening in modern Guangdong, there remains a significant gap concerning the knowledge sources, development logic, and sustainable planning principles underlying these efforts. Therefore, this paper aims to systematically review the development of afforestation and urban greening in modern Guangdong under the influence of advanced Western forestry knowledge, with a special focus on their role in enhancing urban green spaces and sustainable urban planning. By deepening the understanding of the knowledge sources and development logic behind afforestation and urban green space initiatives, this

study seeks to shed light on their significance for sustainable urban and land development in Guangdong. Moreover, it offers new perspectives and methodological approaches that can inform the planning and management of urban green spaces and sustainable forestry development in other rapidly urbanizing regions worldwide.

2. Materials and Methods

A wealth of local historical documents from the modern era provide extensive records of the development of afforestation and urban greening in Guangdong during the modern period, serving as crucial primary sources for this historical study. To ensure the accuracy of the research findings, this paper primarily references primary sources, including various agricultural and forestry journals in modern times, such as Journal of the New Seedlings, Guangdong Agriculture and Forestry Monthly, Agricultural Voice, etc., agricultural journals of the National Sun Yat-sen University, as well as Republican Daily, Municipal Gazette, etc., and relevant republican-era books, totaling 30 historical documents (See Table A1 in Appendix A).

Through text analysis, the aforementioned historical materials were systematically organized and categorized by theme to extract key information related to modern Guangdong afforestation and urban greening, primarily covering the following aspects: (1) Ideological enlightenment—for example, how Yat-sen Sun and returning Chinese scholars promoted Western concepts of afforestation and urban greening through public speeches, published writings, and other channels. (2) Institutional policies and events—such as the dates of Arbor Day, the procedures of tree-planting ceremonies, the establishment time, location, and scale of various forest farms and nurseries, as well as the formulation of forestry regulations. (3) Spatial and landscape dimensions—including the planting and layout patterns of roadside trees, the functions of forest parks, and their relationship with urban planning and national policy. (4) Technological and knowledge transfer—for instance, the introduction of afforestation practices from various countries by Fenzel, the ways in which domestic scholars incorporated foreign experiences and knowledge in afforestation and urban greening, and how such knowledge was localized in implementation.

It should also be noted that the data mentioned in this paper, such as the area of nurseries and forest farms, the types and quantities of trees and statistical rankings, are all original data recorded in historical records. This paper collates these data and incorporates them into the analytical logic. Although not strictly quantitative research, they have empirical significance in supporting arguments and verifying trends.

This paper aims to address the following research questions: (1) Why did Guangdong choose to embrace Western afforestation thought? (2) What did Guangdong learn from the West in afforestation and urban greening practice? (3) How did Guangdong localize and adapt foreign knowledge to create contextually appropriate models of sustainable urban and land development?

3. Results

3.1. The Ideological Enlightenment of Afforestation and Urban Greening

The term “forests” was initially defined by a German scholar named Sadakage as “extensive wild tree species”. However, due to deforestation, the term gradually took on the meaning of “cultivated tree areas” [11]. The evolution of the definition of “forests” reflects the interaction between human society and the natural environment. It not only illustrates the growing awareness of ecological transformation but also marks a pivotal shift toward proactive environmental planning and sustainable land management practices [12]. Therefore, to revitalize forests, the focus must shift from “over exploitation” to “large-scale artificial tree planting and afforestation”.

Yat-sen Sun (1866–1925), dedicated to reforming China, conceived the idea of mobilizing the populace for tree planting and afforestation as early as the late Qing Dynasty. Having studied in Europe and America from a young age, Yat-sen Sun's thoughts and actions were deeply influenced by Western civilization. As early as the late Qing Dynasty, he observed that Western powers were beginning to consciously protect forests. So in 1890 and 1894, he twice approached Chinese officials to raise concerns about deforestation, suggesting that China emulate Western afforestation systems as part of broader national modernization and urban development reforms [13]. Unfortunately, his proposals did not gain traction at that time due to his limited political influence.

After assuming the role of Provisional President of the Republic of China, Yat-sen Sun began to institutionalize afforestation on a national scale. In 1912, after establishing the Provisional Government in Guangzhou, he continued to promote his vision for forest development. Recognizing its value for public welfare and national strength, he collaborated with Daoyang Ling (1888–1993)[1], a returned overseas scholar, to incorporate afforestation into major national policy documents, including The Strategy for Building a Nation (1917), The Outline of National Reconstruction (1924), and The Three Principles of the People (1924)[2].

Through public speeches and planning directives in Guangzhou, Sun emphasized the importance of tree planting in improving the urban environment and laid the conceptual groundwork for transforming Guangzhou into a "garden city"—a notion aligned with early 20th-century Western sustainable planning ideals. In The Strategy for Building a Nation, he explicitly advocated for tree planting as a means to beautify and modernize cities [14]. In The Three Principles of the People, he positioned afforestation as a necessary response to environmental and public health challenges [15].

It is clear that Yat-sen Sun deeply understood the strategic role of afforestation in shaping modern cities and promoting sustainable urban development, an idea that resonated with contemporary Western leaders. Previously, U.S. President Roosevelt remarked", The wealth and strength of a nation depend upon the revival of its forestry". Under Yat-sen Sun's strong advocacy, afforestation and urban green space development began to be recognized in Guangdong as foundational components of modernization and sustainable urban land use planning [16]. At the same time, a cohort of returned Chinese scholars and foreign experts based in Guangdong actively promoted advanced Western afforestation and urban greening concepts, translating them into local policies and practices.

Forestry serves as the foundational infrastructure for sustainable national development, supporting agriculture, industry, transportation, and the provision of essential resources for everyday life. Recognizing this, a number of returning Chinese scholars understood that to promote afforestation as a tool for urban and land development, it was essential to first enhance public understanding of afforestation and its broader societal value. To this end, these scholars actively leveraged their overseas education and experiences to disseminate Western afforestation and urban greening concepts through public lectures, articles, and policy making.

Kutong Huang, a graduate of the Department of Forestry at the University of Tokyo, Japan, later worked as an instructor at the Guangdong Agriculture and Forestry Training Institute and as a technician at the Guangdong Agricultural and Forestry Farm. By comparing forestry laws from different countries, he proposed targeted forest management strategies and viewpoints on artificial afforestation. Between 1916 and 1917, he published a series of articles in Guangdong Agricultural and Forestry Monthly. In his essay On the Neglect of Forests and Suggestions for Their Recovery [17], he introduced forest legislation from Japan and Western nations, advocating for legal regulation of deforestation and tree cutting. Furthermore, based on Dr. Honda Seiroku's Principles of Afforestation, he clarified

the distinctions between natural and artificial forests, urging Guangdong to implement large-scale afforestation as a response to environmental degradation and a cornerstone of sustainable urban development [18].

Jikuan Zeng (1883–1950), a graduate of the Forestry Department of Kagoshima Agricultural School in Japan, later served as a professor in the Department of Agriculture and Forestry at National Sun Yat-sen University and worked as an agricultural and forestry technician. Xianguo Chen, a graduate of the Agronomy Department of Cornell University in the U.S., together with Jikuan Zeng, further advanced the societal influence and emerging functions of forests. Zeng highlighted the etymological origins of "afforestation" from the German term Waldbau, referencing J.W.F. Hager's 1864 book Unterricht Von Waldbau. In his essay The Trend of World Cultures and the Issue of Forest Socialization in the Monthly Agricultural Journal, Zeng discussed international afforestation strategies in response to global forestry crises. Xianguo Chen approached the issue from a systemic perspective, outlining how forestry intersects with agriculture, industry, commerce, and politics. He especially emphasized Western understandings of forests as spaces for public recreation and therapeutic health, which aligned with emerging urban planning priorities [19].

Ke Sun (1891–1973), a graduate of the University of California in the U.S., where he majored in Literature and Law, and the son of Yat-sen Sun, later served as the mayor of Guangzhou. He actively promoted the integration of afforestation into urban planning to create livable and resilient cities. In 1921, influenced by modern Western urban design concepts, Sun published Urban Planning Theory and began applying its principles to the redevelopment of Guangzhou. Regarding recreational space for residents, he wrote [20], "Westerners usually reserve open spaces, create parks of various sizes and playgrounds. Parks are often built in the suburbs, especially near mountains or water. The key to such parks lies in planting trees, creating a natural landscape that gives visitors a sense of a paradise". This illustrates that tree planting was not merely decorative, but a key element of urban green space design, directly influencing site selection and spatial planning in the context of sustainable urban development.

In addition, returning Chinese scholars such as Youheng Tang, Guo Hou, Huanyong Chen, Pengfei Shen, and Jingxin Qi also played important roles in afforestation and urban greening in modern Guangdong. They received systematic education in forestry or botany in countries such as the U.S., Japan, and Germany. Upon returning to China, they were active in forestry experimental stations, the Department of Agriculture and Forestry, universities, and research institutions, introducing advanced foreign theories and techniques of afforestation to Guangdong (Table 1).

Amid these political and intellectual reforms, the returning scholars upheld the principle of "scientific salvation of the country", promoting an international vision for national revitalization. Their efforts reflect an early form of sustainable planning rooted in science, transnational knowledge transfer, and the localization of Western afforestation ideals. This wave of thought not only reshaped Guangdong's ecological landscape but also laid the foundation for the integration of green space into modern urban governance.

3.2. An Exploration of the Afforestation and Urban Greening Practice

To encourage tree planting among the populace, the U.S. was the first to establish Arbor Day. In 1915, during a memorial for Civil War veterans, American educator Moina Michael (1869–1944) tree planting activities with the commemoration of significant individuals [21].

Table 1. Introduction to the main modern returning Chinese scholars in Lingnan area who studied Forestry in the West.

Name	Birthplace Birth & Death	Occupation	Representative Publications	Majors Abroad Region
Yat-sen Sun	Xiangshan, GD 1866–1925	Provisional President of the Republic of China.	Three Principles of the People; The Strategy for Building a Nation; The Outline of National Reconstruction.	English; Mathematics. The U.S.
Ke Sun	Xiangshan, GD (1891–1973)	Guangzhou's first mayor.	Urban Planning Theory; Capital Planning; Provisional Regulations of Guangzhou.	Literature; Law. The U.S., Columbia
Kutong Huang	Meixian, GD ———	Teacher and Technician at GD Agricultural and Forestry College; Instructor at GD Agricultural School; Dean of SANSYU.	Opinions on the Abandonment of Forests and Its Remediation; On the Relationship between Forests and Water Management and the Plan for Afforestation for Flood Prevention; A Brief Discussion on Forest Protection.	Economics; Forestry; Agriculture. Japan, France
Xianguo Chen	Chenhai, GD ———	Associate Professor at Lingnan University; Technician at Guangzhou Agricultural Products Inspection Institute.	Our Understanding of Forests; Our Understanding of Afforestation Movements.	Agriculture. The U.S., Columbia
Jikuan Zeng	Fengdu, SC 1883–1950	Technical Expert and Professor at SANSYU.	Trends in Global Cultures and the Issue of Forest Socialization; Guidelines for Agricultural and Forestry Development in GD; Several Fundamental Issues in Forest Development in GD.	Forestry. Japan
Youheng Tang	Zhuhai, GD 1884–1958	Agricultural Technician, U.S.; Director and Agronomist at GD Agricultural and Forestry College.	Outline of Agricultural and Forestry; Construction in Zhongshan Model County.	Physics; Chemistry; Agricultural Science. The U.S.
Huanyong Chen	Xinhui, GD 1890–1971	Dean of SANSYU; Founder of the Institute of Agriculture and Forestry Plants at SANSYU.	Genus Euodia Plants in GD; Economic Forests in China; Supplement to the Catalog of Chinese Trees.	Forestry. The U.S.
Pengfei Shen	Panyu, GD 1893–1983	Director of Forestry Department, GD Agricultural Specialized School; Director, SANSYU.	The Relationship Between Forests and Industry; The Relationship Between Forests and Agriculture.	Forestry The U.S.
Jinxin Qi	Haxian, Anhui 1900–1973	Professor at SANSYU.	Translated many works of Fenzel	Forestry Germany

Notes: The Abbreviations: GD—Guangdong; SANSYU—the School of Agriculture at National Sun Yat-sen University; FMFFBM—the First Model Forest Farm at Baiyun Mountain.

China adopted this practice by integrating it with the remembrance of Yat-sen Sun [22]. Arbor Day in China originated in 1915, initially observed on Tomb Sweeping Day. In 1916, Qinglan Zhu (1874–1941), the governor of Guangdong Province, promoted large-scale tree planting on Arbor Day. As part of early sustainable urban initiatives, he invited political figures to lead by example in tree planting and encouraged student participation from primary and secondary schools (Figure 1a) [23]. On 12 March 1925, Arbor Day was moved to coincide with the anniversary of Yat-sen Sun's death, further intertwining tree planting with national memory. Political scientist Seymour Martin Lipset (1922–2006) emphasized that personal commemorations play a vital role in constructing political symbols [24]. By linking afforestation with the symbolic heritage of Yat-sen Sun, the Nationalist government transformed a basic environmental initiative into a public ritual of ideological education and civic engagement. Citizens who admired Sun were encouraged to participate more actively in greening activities.

To institutionalize this connection, Guangdong's political leadership introduced a formalized tree-planting ceremony. The event included flag salutes, the reading of Yat-sen Sun's testament, moments of silence, patriotic speeches, and the singing of tree-planting songs [25]. This ceremony created a politically charged yet socially inclusive space that emphasized national identity, while simultaneously embedding the values of environmental stewardship into daily civic life. Such practices exemplify how afforestation became not only an environmental goal but also a socially embedded strategy within sustainable planning frameworks. By transforming Arbor Day into a ritualized, participatory practice

of urban green space promotion, the Guangdong government successfully increased public involvement and environmental awareness.

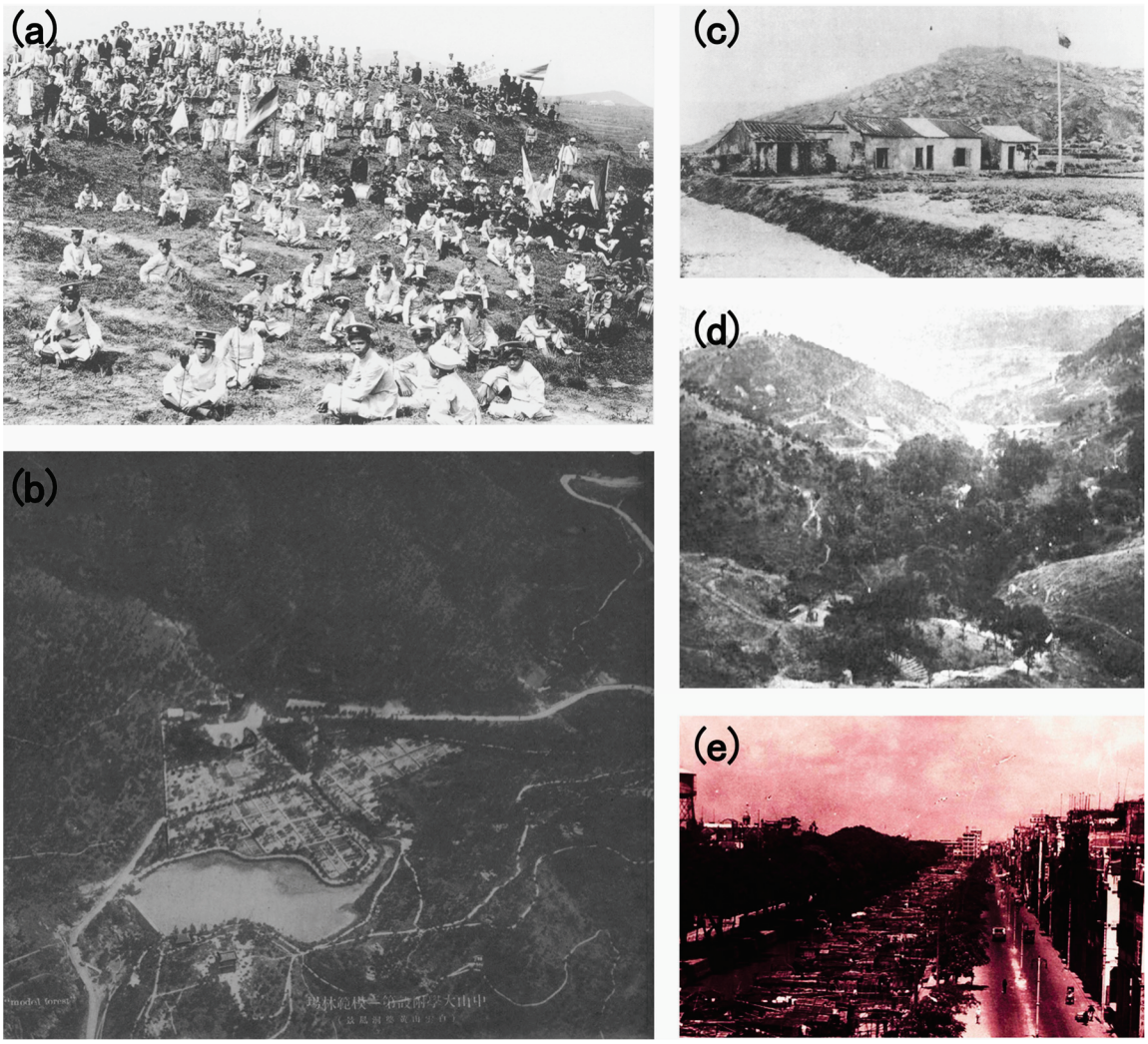

Figure 1. Historical Photographs. (**a**) Guangzhou students planting trees on 4 April 1916 at Baiyun Mountain in Guangzhou (Source: Photo Record of Guangdong in 20th Century, 2002); (**b**) Aerial View of the First Model Forest Farm at Baiyun Mountain (Source: The Popular Illustrated Newspaper, 1934); (**c**) Before reforestation, Baiyun Mountain (Source: Photo Record of Guangdong in 20th Century, 1900); (**d**) After reforestation, Baiyun Mountain (Source: Guangzhou Guide, 1934); (**e**) Street Trees along 623 Road in Guangzhou, 1925 (Source: Sun Yat-sen Library of Guangdong Province, 2002).

The integration of tree planting with the commemoration of Yat-sen Sun was thus not merely symbolic, but also a strategic cultural and political innovation. It enhanced the visibility and legitimacy of green initiatives and allowed environmental actions to be grounded in nationalist sentiment and transnational cultural adaptation [26]. This approach elevated afforestation into a form of sustainable urban social practice, intertwining environmental consciousness with civic identity, and reinforcing long-term public commitment to green space creation. Historical records document the tree-planting achievements of various counties in Guangdong in 1931 (Table 2), demonstrating the significant impact of this cultural and political innovation in advancing local green development.

Table 2. Afforestation Achievements Reported by Various County and City Governments (1931).

County/City	Area (mu) [2]	Number of Trees (zhang) [1]	County/City	Road Length	Number of Trees
Panyu	70.7	10,000	Puning	720	400
Deqing	90	50,000	Chixi	3600	4000
Zhongshan	9	12,430	Jiangmen	270	250
Baoan	151.5	5500	Zijin	360	500
Guangning	20	7100	Haifeng	70	800
Heping	5	7700	Xingning	1260	2600
Renhua	150	5000	Lingshan	1500	1356
Lianjiang	49	331,600	Dingan	360	300
Dianbai	250	31,000	Lingao	500	520
Yunfu	310.1	5400	Taishan	270	475
Sihui	50	30,000	Jieyang	180	100
Hepu	40	21,000	Yunan	360	600
Huaxian	110	9000			
Fengshun	20	6400			
Wuchuan	1800.2	6000			

Source: Tree Planting Achievements in Guangdong Counties and Cities in the Past Twenty Years (1931)
Notes: [1] zhang = 3.33 m; [2] mu = 666.67 m^2

It should also be noted that, from a social observation perspective, tree-planting activities have a highly mobilizing effect on the public. They not only attract widespread participation from local officials, school teachers and students, social organizations, and ordinary citizens, but also evoke strong emotional resonance and a sense of political belonging among the public. This collective activity has transformed tree planting from an isolated official project into an important event that permeates daily life and is embedded in the public memory of the local community. Clearly, tree-planting activities reflect the initial state of political mobilization and social participation mechanisms in Guangdong's modern public greening initiatives.

As the ideology of tree planting became ingrained in the public consciousness, the Guangdong provincial government began to promote the development of nurseries and forest farms to provide the necessary support for large-scale afforestation. This shift marked a transition from symbolic tree-planting campaigns to the institutional infrastructure required for long-term sustainable land and forestry management. German forester Gottlieb Fenzel (1896–1936), a key figure in this transformation, made outstanding contributions to the establishment of nurseries and forest farms in Guangdong during the modern period[3].

Fenzel first emphasized to the people of Guangdong the critical necessity of establishing nurseries and forest farms as foundational components of rational land use and sustainable resource planning. Drawing a comparison between Guangdong and Germany, he noted that while Germany had a much higher population density, it also benefited from more advanced industrial development. In contrast, Guangdong, despite its population of nearly 30 million, lagged significantly behind Europe in economic growth. Fenzel attributed this disparity in part to Guangdong's severely underdeveloped forestry sector. He observed [27], "Guangdong residents had no idea of cultivating mountainous land. In Europe, 25% of the land in each country is used for afforestation, resulting in only 10–15% being wasteland. In contrast, Guangdong's former forests were mostly burned, with the remaining survivors accounting for only 1% of the total area, leaving the rest, 92%, as barren land". His observations not only highlighted a forestry crisis but also pointed to inefficient land spatial patterns and the urgent need for ecological restoration and planning interventions.

To raise public awareness and promote forest recovery, Fenzel published numerous educational articles in agricultural and forestry journals. These writings aimed to foster public understanding of afforestation as a scientific practice, and to build institutional capacity for the creation of sustainable green infrastructure across urban and rural territories.

While actively promoting awareness, Fenzel also engaged in the practical implementation of sustainable forestry infrastructure. In 1927, after observing 18,000 mu of abandoned land on Baiyun Mountain in Guangzhou, he requested and was granted responsibility for reforesting the area. In 1928, with the goal of developing the forestry sector, the Guangdong provincial government established the Forestry Bureau and appointed Fenzel as its Deputy Director [28]. Following this, he introduced advanced German afforestation theories and techniques, implementing them first at the First Model Forest Farm on Baiyun Mountain and later at a major nursery in Chaozhou.

These projects represented early prototypes of multifunctional green space planning, with each site tailored to local topographic and environmental conditions. The Baiyun Mountain Forest Farm spanned 1453 hectares and was divided into 27 forest zones, including five nurseries, one arboretum, eight experimental zones, one model forest avenue, and 22 small forest avenues [29] (Figure 1b). Data from April 1935 show that under Fenzel's management, all zones had been afforested (Figure 1c,d), totaling 2,592,276 trees, with Masson pine comprising 96.1% of the total stock (Table 3) [30]. To further enhance the forest farm' s functionality, Fenzel advocated for infrastructure that supported both research and public engagement. Facilities such as a forest farm office, workers' dormitories, multiple rest pavilions, and a library were added to support education, leisure, and knowledge dissemination, thus transforming the site into a comprehensive node of green infrastructure and civic interaction. This model contributed to the optimization of land use patterns and reinforced forest farms as spaces of public value.

Table 3. Overview of Trees in the First Model Forest Farm at Baiyun Mountain.

Components	Tree Species	Total (Rate)
Forestry	*Broadleaf Trees: Camphor, Chestnut, Autumn Maple, Silver Birch, Oil Tea, syzygium jambos, Eucalyptus, Acacia confusa,* etc.	45,409 (1.8%)
	Deciduous Broadleaf Trees: Melia azedarach, red beans, wutong, tung oil, kapok, green plum, teak, Chinese toon, Phoenix wood, Myanmar acacia, plum, etc.	24,895 (0.9%)
	Broad-leaved fir.	31,282 (1.2%)
	Masson Pine.	242,433 (96.1%)
Nursery	*Taiwanese acacia, Eucalyptus, Burmese acacia, Philippine acacia, camphor tree, tung oil tree, Camellia oleifera, broad-leaved fir, Bauhinia, etc.*	250,225
Experimental Zone	*Eucalyptus, Acacia formosana, Albizia myanmar, silver birch, camphor tree, tung tree, camellia oleifera, wutong tree, broadleaf fir, masson pine, Indian pine, American pine, water pine, redbud, golden tree, chestnut, Chinese tallow, kapok, Chinese toon, Chinese rosewood, Indian rosewood, teak, saponin, autumn maple, chinaberry, syzygium jambos, etc.*	4376
Herbarium	*Phoenix wood, red bean tree, Philippine red bean tree, Myanmar acacia, Leucaena leucocephala, Chinese yellow locust, Cercis chinensis, silver birch, safflower camellia oleifera, golden tree, sapling tree, water yellow bark tree, cattail, camptotheca acuminata, teak, eucalyptus, water pine, American water pine, Casuarina equisetifolia, boxwood, broadleaf cedar, cryptomeria fortunei, cypress, autumn maple, chestnut, paulownia, wutong, Yunnan tung, masson pine, Indian pine, American pine, Dawang pine, Luohansong, soap tree Robinia pseudoacacia, Indian acacia, mountain jujube, Chinese toon, Arabic acacia, yellow acacia, etc.*	

Source: Current status of National Sun Yat-sen University, 1935.

The Chaozhou nursery, by contrast, consisted of a main nursery and several branch nurseries, each with a distinct functional orientation. The main nursery, covering 228 mu, was divided into seedling cultivation areas, experimental plots, and dedicated afforestation zones. Initial plantings focused on *Pinus densiflora Siebold & Zucc.*, complemented by *Eucalyptus globulus, Acacia confusa Merr.*, and later species such as *Albizia lebbeck (Linn.) Benth., Sapium sebiferum (Linn.) Roxb.*, and *Melia azedarace* L [31]. The branch nurseries near

the western entrance of Chaozhou were deliberately positioned to serve as public-facing green spaces, with easy access for residents. Fenzel also introduced a "foreign tree zone" showcasing non-native species with detailed botanical and economic annotations. This transformed the nursery into a living educational exhibit, enriching biodiversity while fostering public environmental literacy [32].

It can be observed that, in terms of site utilization, the different functional configurations reflect Fenzel's modern and pragmatic planning approach to land-use optimization. Regarding planting methods, Fenzel clearly adopted differentiated strategies. At the Baiyun Mountain Forest Farm, he prioritized monoculture of native species such as *Pinus massoniana Lamb*., while at the nursery in Chaozhou, a diversified planting strategy was employed to support experimentation, education, and biodiversity enhancement. This divergence is rooted in practical planning logic: monoculture facilitates large-scale forest operations and standardized management, requiring fewer technical inputs, whereas nurseries, by nature, permit lower-risk experimentation and therefore can support a broader range of species for research and pedagogical purposes.

Fenzel's practical work at the Baiyun Mountain Model Forest Farm and Chaozhou Nursery, including spatial zoning, species diversity experiments, and tree species adaptability verification, not only represents the localization of German forestry knowledge but also embodies the early practice of modern "evidence-based planning". Through field experiments, he accumulated data, developed site-specific planting strategies, and utilized plot studies to advance research and education. This not only optimized land use but also provided a reference for subsequent greening and landscape management efforts.

Under Fenzel's leadership, various regions across Guangdong began constructing forest farms and nurseries. To enhance public knowledge and operational efficiency, he authored Practical Methods for Afforestation and Nursery Facilities in Guangdong. This handbook integrated European forestry knowledge with local conditions, drawing directly from his experience at Baiyun Mountain, and offered a systematic, localized approach to nursery construction and afforestation. It was recognized at the time as a work that "can alleviate the lack of general afforestation knowledge and indeed herald the revitalization of Guangdong's forestry" [33].

By 1930, in addition to the Baiyun Mountain and Chaozhou sites, new forest farms had been established in Nanhua, Shaoguan, Luofu, Dinghu, and Deqing, with the total number of such facilities across Guangdong exceeding 20 (Table 4). These facilities were widely distributed, encompassing small urban-adjacent nurseries for street and park greening as well as large mountainous plantations for the cultivation of commercial and protective forests. Annual seedling production at these nurseries ranged from several thousand to several hundred thousand, covering evergreen trees, broadleaf species, and economically valuable tree varieties. Moreover, management practices and afforestation techniques at these sites increasingly incorporated advanced methodologies, including systematic seedling propagation, thinning, and experimental afforestation. Collectively, these efforts substantially enhanced both forestry production and urban greening capacity in Guangdong, laying a solid foundation for subsequent large-scale tree planting and urban landscaping initiatives.

Additionally, according to the national tree planting statistics for 1933 (Figure 2), Guangdong had approximately 34,074 hectares of forest land and approximately 370.56 million tree seedlings, ranking among the top provinces nationwide. While its forest land area was second only to Hebei, Guangdong led Hebei in terms of the number of tree seedlings. Compared to other southern provinces such as Guangxi, Fujian, and Chaozhou, Guangdong significantly surpassed most provinces in both forest land area and number of seedlings, demonstrating its clear advantages in afforestation and seedling cultivation. Considering the construction of model forest farms and nurseries at the time, it is evident that Guang-

dong achieved outstanding accomplishments in modern afforestation and urban greening practices, serving as a leading national model.

Table 4. Overview of the Establishment of Forest Nurseries in Guangdong (As of 1930).

Affiliated Unit	Nursery Name Area (mu)	Location Building Time	Annual Seedling Output	Nursery Features
Construction Agency	Chao'an Model Forest Farm 53.55	Chaoyan Mountain, CZ 1929	Several hundred thousand	Well-organized planning; Efficient irrigation system.
	Nanhua Model Forest Farm 46.3	Lianhua Mountain, SG 1929	Over ten thousand	Easy transportation
	Dinghu Model Forest Farm 20	Dinghu Mountain, ZQ 1930	Over ten thousand	————
	Lofu Model Forest Farm 21.78	Lofu Mountain, HZ 1930	Over ten thousand	Transformed into Lofu Mountain Park in 1934
	Deqing Model Forest Farm 8.65	Xiangshan, DQ 1930	Over ten thousand	Difficult to manage
	Chashan Model Forest Farm 20	Shipai village, GZ 1930	Suitable for the tree-planting needs of GZ	A reforestation site of the tree-planting movement
Agricultural College, Sun Yat-sen University	First Model Forest Farm Over 10	Baiyun Mountain, GZ 1927	Several hundred thousand	Direct seeding method
	The Second Farm Over 100	Shipai village, GZ 1927	————	Native and foreign tree species
	Chaozhou Nursery Over 200	CZ 1927	————	Including seedling cultivation and afforestation areas
Chao-Mei River Control Branch (formerly Hanjiang River Control Office)	Hanjiang Central Nursery 70	Upper reaches of the Hanjiang River mouth 1927	20–30 thousand	Direct seeding method
	Xingning Branch Nursery 10	Eastern suburbs of Xingning 1928	Tens of thousands	Suitable for afforestation
	Wuhua Branch Nursery 8–9	East of Wuhua 1927	Tens of thousands	Seedlings are provided for villagers
	Meixian Branch Nursery Over 10	West of Meixian 1928	Tens of thousands	Hard transportation
	Pingyuan Branch Nursery 20	Near the county town 1929	Tens of thousands	Three nursery areas

Source: Special Issue on Tree Planting on the Seventh Anniversary of the Premier's Death (1932). Notes: (1) The Abbreviations: CZ—Chaozhou; SG—Shaoguan; ZQ—Zhaoqing; HZ—Huizhou; DQ—Deqing; GZ—Guzngzhou; (2) Apart from all the mentioned above, there are at least seven county-owned or private nurseries, including Zhongshan County Nursery (1930), Fangcheng County Nursery (1929), Renhua County Nursery (1929), Bao'an County Nursery (1930), etc.

It is evident that in this movement, imported forestry knowledge was not merely transplanted but skillfully localized, aligning with the Kuomintang's broader development strategy of "adopting Western techniques to meet China's needs". The widespread establishment of nurseries and forest farms during this period not only represented a major milestone in the modernization of Guangdong's ecological infrastructure but also laid a foundational framework for the later development of road landscapes, forest parks, and urban green spaces.

There is no doubt that, as a pioneer in China's "green wave", Guangdong demonstrated an early form of sustainable land and urban planning. Despite limited prior experience, it took the lead in integrating ecological restoration with long-term development goals, and embarked on a trajectory of urban–rural spatial transformation that resonates with today's sustainable planning principles.

The concept of linking street trees with urban beautification emerged in the mid-19th century. In major cities across Europe and America, it became a common practice to plant rows of trees along both sides of roads, forming what are known as "street trees". [34] As early as 1853, Paris began transforming its urban landscape with tree-lined boulevards, reshaping not only traffic circulation but also the visual and ecological character of the city [35]. By the early 20th century, the U.S. had launched a nationwide

urban beautification movement in which green infrastructure became central to road design. Multiple states emphasized the importance of tree planting: a California delegate noted, "Road beautification issues . . . We have 600 miles of roads lined with planned tree plantings"; Representative from Chowchilla said, "Next year's program . . . The most important thing is to plan for roadside trees"; The Isle of Ruth delegate said, "There is no point in having straight roads, now we are trying to make the new roads go where the scenery is the best, and all the small trees that were there before have been eliminated and replaced by new ones"; The representative of Michigan said, "We planted 140,000 palm trees last spring, and we shall be very strict everywhere in the future, so that there will not be an unattractive road in the whole State of Michigan" [36]. Clearly, street trees had become symbolic of modern, livable, and scenic urban planning.

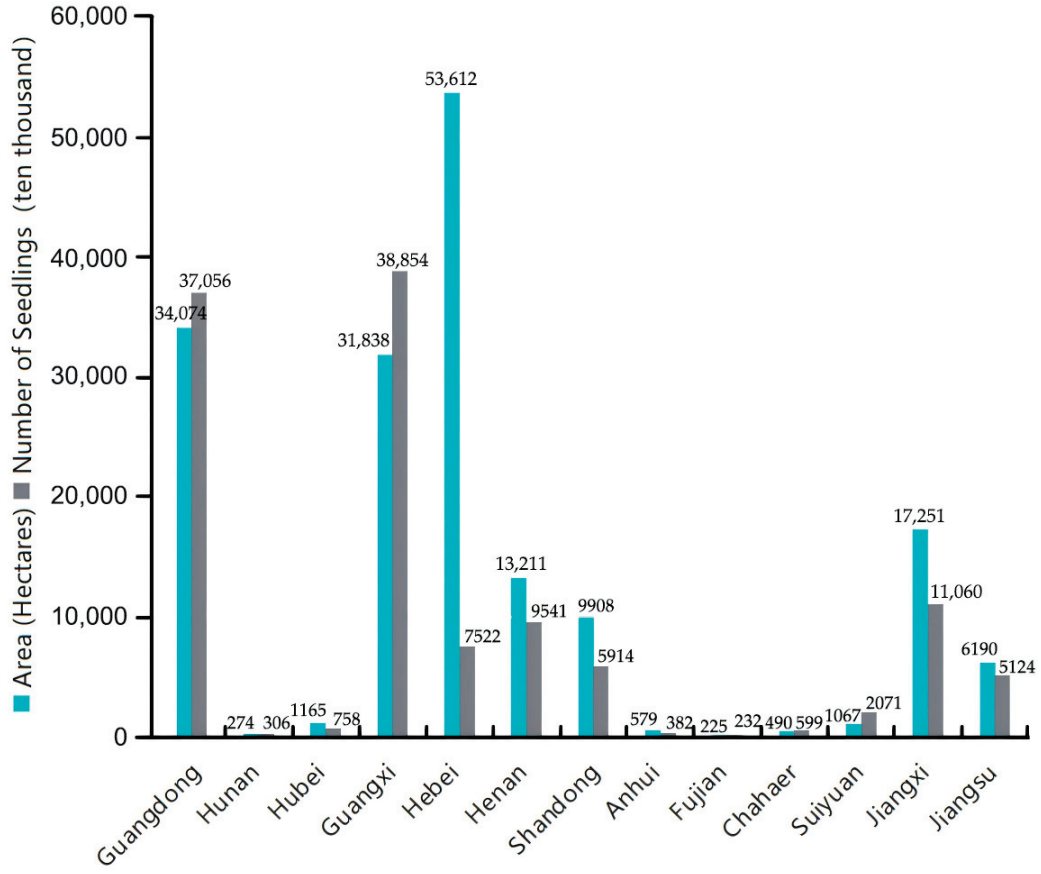

Figure 2. Forest Plantation Statistics in Various Provinces of China in 1933. (Source: Forestry: Statistical Tables of Forest Planting by Province, 1933). Notes: The survey data, obtained from the Ministry of Industry's Statistical Department and reported by various provinces and cities, excludes non-reporting counties and cities from the calculation. Despite incomplete reporting at the county and city level, the effectiveness of afforestation in Guangdong is evident from the known planting areas and corresponding tree counts.

In the 1920s, Guangdong began adopting the practice of planting street trees, drawing inspiration from Western urban models. This occurred during a crucial period of modern urban transformation, when city walls were being demolished to expand road systems. Yet, newly built roads often lacked vitality and comfort. Kuomintang veteran Sen Lin (1868–1943) criticized the exposed condition of pedestrians, arguing: "As the public walks on the streets, they are drenched in sweat. We should plant street trees, just like in Paris, London, and Berlin, to shield the people from scorching heat and stifling dust"[4] This raised key questions for Guangdong's planners: How should street trees be arranged to balance aesthetics, shade, and spatial efficiency? What planting strategies suited local climate

and urban form? In 1924, the Municipal Gazette introduced tree planting techniques from Berlin and Paris [37]. In 1928, Professor Guoren Jiang from the College of Agriculture at National Central University illustrated practical methods for roadside greening (Figure 3). By 1930, highway personnel in Jiepu, Guangdong had begun to synthesize Chinese and Western experiences, gradually developing a regionally adapted model of sustainable streetscape planning [38].

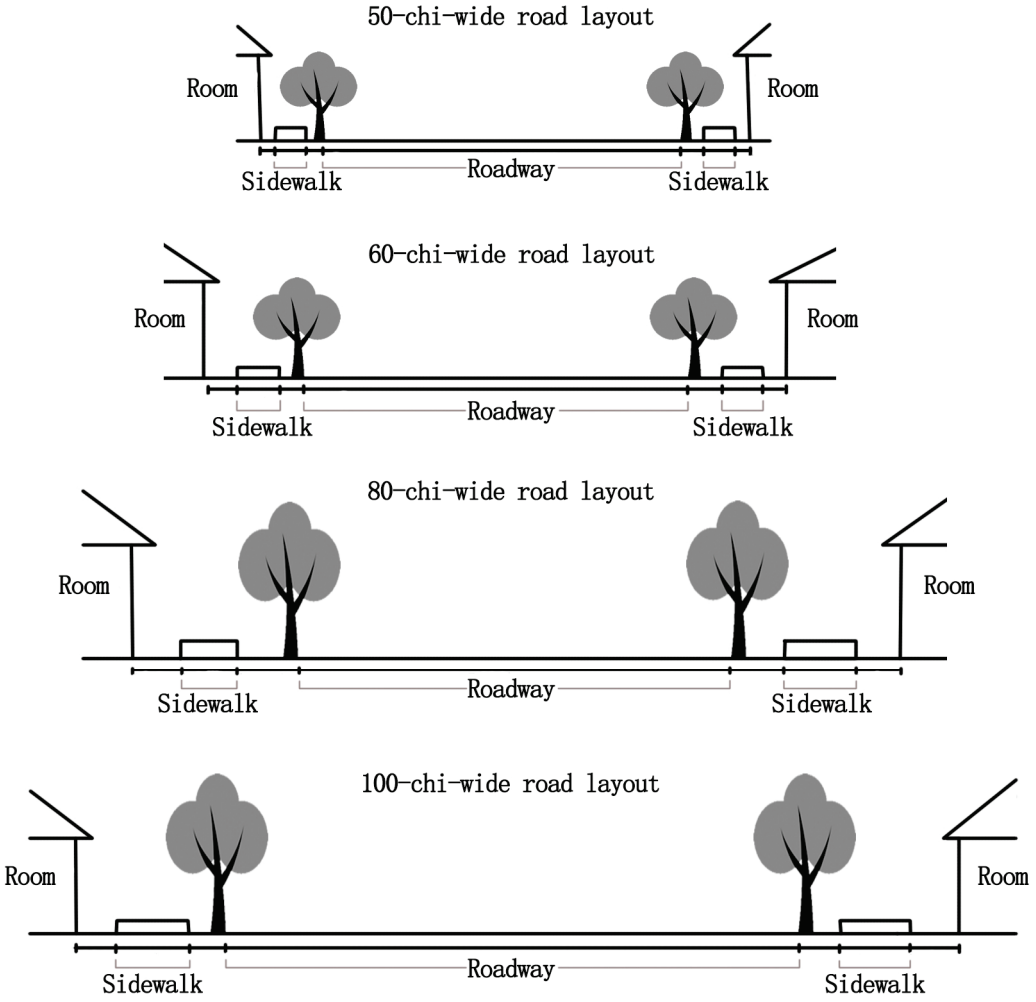

Figure 3. The Arrangement Method of Street Trees on Wide and Narrow Roads. (Source: Journal of the College of Agriculture of the National Central University, 1928; Notes: 1 Chi = 0.33 m).

As a result, street trees were increasingly incorporated into Guangdong's road planning not merely as ornamentation, but as functional, climate-sensitive urban elements. Their implementation reflects early efforts in urban greening, thermal comfort enhancement, and sustainable spatial organization, aligning closely with today's principles of climate-resilient and people-centered urban development.

In the early stages of planting street trees, Guangdong faced significant challenges, with one of the greatest being the low survival rate of transplanted seedlings. To address this issue, the government looked to international practices, particularly those in Paris. For instance, Paris selected mature saplings for roadside planting, which not only improved survival rates but also helped resist soil acidification and human interference [39]. Prior to the widespread planting of roadside trees, Guangdong had already established numerous model forest farms and nurseries, which laid the foundation for sustainable urban greening. Species such as *Autumn maple, Albizzia julibrissin,* and *Albizzia falcata* had already matured in these forest farms, reaching 1.2 to 1.5 m in height. Drawing on Western practices, local

authorities recognized the suitability of these native species—both in ecological adaptability and aesthetic value—as ideal candidates for urban roadside planting.

Despite encountering continued difficulties in roadside greening [37], Guangdong's approach evolved through iterative learning and adaptive experimentation. By the 1930s, significant progress had been made in the implementation of tree-lined urban streets. Between 1925 and 1929, the Public Works Bureau of Guangzhou systematically planted dense trees and shrubs along major urban thoroughfares, including Weixin Road, Huifux Road, Wende Road, Yushan Road, and 623 Road (Figure 1e). Importantly, the act of roadside tree planting transcended ecological and functional objectives. It carried political and symbolic meaning, commemorating Yat-sen Sun and affirming governance principles rooted in the Three Principles of the People. These green spaces became vehicles for promoting modern civic ideals, reflecting both the people's aspirations for improved urban living and the government's vision of sustainable modernization.

In the 18th–19th centuries, with improvements in living standards, Western countries' expectations of forests extended beyond traditional uses such as timber production and charcoal making. Instead, forests began to be associated with public health and well-being. The integration of recreational functions into forest environments gave rise to forest parks, which enhanced urban green space while providing restorative environments for both body and mind [40].

The concept of forest parks originated in Germany. In 1895, Germany designated the Lindenthal area on the western outskirts of Cologne as an urban forest, incorporating recreational infrastructure into it [41]. This marked the inception of the forest park model. Recognizing the therapeutic benefits of natural environments, other European countries soon followed suit. By the early 20th century, the U.S. had allocated 27% of its forest areas to recreational use, with the UK and Norway allocating 27% and 25%, respectively [42]. In contrast, only 47% of U.S. forests were used for timber production. These figures illustrate a growing shift in forest policy toward human-centered, multifunctional land use—an essential feature of sustainable planning.

The widespread recreational use of forest areas in Western countries sparked a desire in China to establish similar spaces. During the 1929 Afforestation Campaign Week, forestry official Xianguo Chen emphasized [19] the multi-functionality of forests, stating in Guangzhou's Central Park: "In America, I visited a national park with magnificent scale... forests serve not only ecological but also recreational functions. We aspire to create such parks in China where people can gather and enjoy themselves". In 1931, the Ministry of Industry issued the first order to build forest parks. Minister Xiangxi Kong emphasized [43], "In Western countries, forests are recreational areas. In our country, with a concentrated population in provincial capitals, it is urgent to use existing forests or spacious areas for park construction, promoting urban landscapes and public health". Following this national policy, the Guangdong Agriculture and Forestry Bureau initiated preparations for forest parks in the province.

Guangdong selected Zhongshan Park in Shipai, Guangzhou, as the province's first forest park, in line with the construction criteria outlined in the Guangzhou Municipal Gazette, which emphasized adequate area, topographical advantage, and ease of access For Guangdong, Baiyun Mountain Park and Zhongshan Park in Shipai best met these conditions. Compared to Baiyun Mountain Park, Zhongshan Park was considered more suitable due to its denser tree coverage and stronger symbolic significance.

Shipai Forest Park is a representative example of multifunctional green infrastructure, serving simultaneously as a forest park [44–47] and a memorial space dedicated to Yat-sen Sun. In fact, when Guangzhou chose to build Sun Yat-sen Park, it took into consideration Sun Yat-sen's connection with tree planting and afforestation, and selected Shipai Forest

Farm as the site. The Shibai Forest Farm was the largest forest farm in Guangzhou at the time, covering an area of over 5600 acres and planting tens of thousands of trees annually [48]. From the launch of Guangdong's afforestation campaign until 1931, the Shibai Forest Farm had cultivated 121,560 saplings [49,50]. When considering the construction of a forest park, the Guangdong government also linked it to Sun Yat-sen, and due to its abundant forest resources, it was converted into a forest park.

Furthermore, the establishment of Shipai Forest Park marked the integration of afforestation with public green space development, embedding a strong sense of national symbolism into the landscape. In February 1937, a large-scale tree-planting campaign was held here, with over 1000 participants—from government departments, social organizations, schools, and the general public—planting more than 2000 trees [50]. This cross-class public movement combined elements of "ritualization" and "everyday life", and local newspapers highlighted its dual values of "landscape education" and "national responsibility", guiding the public to associate greening with national rejuvenation. In this way, the concept of "afforestation" gradually shed its purely technical connotations in public discourse, transforming into a social practice that integrated political mobilization, public education, and community participation. By commemorating Yat-sen Sun, the Guangdong provincial government incorporated the forest park into the narrative of modern nation-building. As a material embodiment of the political ideals of the Three Principles of the People, it functioned not only as urban infrastructure, ecological resource, and public recreational space, but also as a venue for ideological expression—demonstrating an integrated model of land development in which environmental, social, and symbolic values were co-produced and mutually reinforced.

3.3. Formulation of Forestry Legal Regulations

In the process of Guangdong citizens actively participating in afforestation practices, several challenges emerged. These included misunderstandings among citizens regarding the purpose of tree planting, confusion in the responsibilities of government departments, persistent unauthorized logging by ignorant citizens, and a lack of post-planting tree care. To further clarify the objectives of forestry development and enhance the administrative and management system, Guangdong initiated the formulation of a series of legal regulations.

The first comprehensive forest regulation in Guangdong, the Provisional Forest Regulations of Guangdong Province, originated from Fenzel's May 1928 Draft of the Provisional Forest Regulations of Guangdong Province (referred to as the "Draft"). The "Draft" served as a foundation for the provincial government's forestry laws. It comprised five chapters covering general regulations, economic forests, forest policing, protective forests, and reward/punishment. Fenzel assimilated global forestry law principles, drawing from German, Bavarian, French, Hungarian, Russian, Swiss, and Italian laws. Actively comparing Guangdong's conditions with those of Western countries, he also tailored regional regulations. For example, Article 47 was applicable only in China, rarely mentioned in the forest laws of European countries. Article 49, following China's mandatory afforestation law, stipulated that the government was not responsible for afforestation costs, whereas governments in European countries often bore such costs [27]. Although the "Draft" was eventually revoked two years later due to inadequacies in its content, it paved the way for the formulation of forestry laws in Guangdong, holding particular significance as Guangdong lacked experience in forestry law formulation at that time.

After studying various forest regulations from Western countries, Guangdong formulated multiple forestry regulations, with the peak period in 1930. In September of that year, the province issued the Provisional Regulations for Afforestation on Idle Land in Guangdong Province and the Regulations on Restrictions for Afforestation on Idle Land in

Guangdong Province. In December, during the 126th meeting of the Guangdong Provincial Government, eight forestry regulations were simultaneously promulgated, covering group afforestation, incentive mechanisms, management of private and public forests, as well as the composition of forestry institutions. Despite Guangdong's developmental lag compared to Western countries, the adoption of Western ideas not only prompted practical initiatives but also propelled the province to keep pace with Western forestry development in legal formulation, surpassing other provinces in China.

4. Discussion

Guangdong's various explorations in afforestation and urban greening during the modern era not only reflected the modernization aspirations of "Western learning for practical use" at the time, but also, to some extent, laid the groundwork for today's green development philosophy. Guided by Yat-sen Sun's vision of Guangzhou as a "garden city", and through the construction of forestry farms, nurseries, street trees, and forest parks, a three-pronged approach to greening was gradually established, combining "political commemoration, ecological construction, and public mobilization". This experience provided an important ideological foundation for the evolution of contemporary green policy systems.

In the new era, Guangdong has continued to advance the systematic planning of urban ecological spaces through policies such as the "Green and Beautiful Guangdong Ecological Construction" initiative and the "Park City" development program. These policies not only reflect local governments' sustained focus on green development but also build upon and deepen the public greening concepts and practices that have evolved since modern times. Many specific measures, such as the long-standing Arbor Day system and its ongoing updates in promotional formats, the exploration of multifunctional forest parks (covering health and wellness, education, disaster prevention, and research), and the growing emphasis on the synergistic relationship between street tree landscapes and urban aesthetics, can be seen as extensions and transformations of modern ideas and practices at the contemporary institutional level.

Furthermore, Guangdong has continuously introduced information technology, legal frameworks, and social collaborative mechanisms into its modern green governance system, transforming the afforestation methods, which were primarily based on political mobilization since modern times, into a composite governance model involving multi-stakeholder participation and driven by data. For instance, the " Green and Beautiful Guangdong Ecological Construction" project not only established a scientific indicator system but also guided the public to participate in urban greening through methods such as "adopt-a-tree" and the "community forest chief system", thereby strengthening the active role of the populace in public ecological affairs. This broad participation mechanism shares a profound linkage of inheritance and evolution with the methods used in modern Guangdong to mobilize the public for afforestation through schools, associations, and trade unions.

In summary, Guangdong's afforestation and greening practices in the modern era have not merely been historical events but have transformed into a conceptual legacy and institutional inertia, continuously shaping the green landscape of local governance today. This deep interaction between history and the present not only reveals the historical foundations of regional green policies but also provides empirical grounding for understanding the logic of ecological governance within Chinese modernization. Furthermore, it opens up avenues for further in-depth exploration in future research.

5. Conclusions

Taking Guangdong as the case, this study examines how Western modern forestry thought were ideologically embraced, locally adapted, and institutionally embedded in modern Guangdong's afforestation and urban greening efforts. The main findings are summarized as follows:

(1) In ideology, returning Chinese scholars, such as Yat-sen Sun, Ke Sun, Kutong Huang, and Xianguo Chen, as well as foreign foresters like Fenzel, leveraged their overseas education to actively convey the necessity of afforestation to the public through various media, ultimately raising societal awareness of ecological issues.

(2) In practice, first, the introduction of Arbor Day in the U.S. inspired the province to institutionalize afforestation through public rituals, symbolically linking tree planting with the commemoration of Yat-sen Sun—thereby embedding ecological practice into political culture and civic identity. Second, Fenzel applied site-specific afforestation strategies and advanced planning logic to nurseries and forest farms, demonstrating localized models of sustainable land use. Additionally, drawing on Western concepts of street trees and forest recreation, Guangdong constructed tree-lined avenues and forest parks, enhancing urban aesthetics and comfort while creating new green spaces with ecological, cultural, and political functions.

(3) In regulation, Guangdong formulated forestry laws inspired by Western models. Starting with the Draft of the Provisional Forest Regulations of Guangdong Province and followed by the intensive issuance of multiple afforestation and forest administration regulations in 1930, Guangdong effectively addressed the management challenges in urban greening practices and promoted the institutionalization of urban green space development. This legal framework not only provided a sustainable governance structure for urban greening but also offered valuable green governance experience for other regions in China.

(4) Historical insights and contemporary continuity: These modern practices continue to have relevance in contemporary Guangdong. The current "Green and Beautiful Guangdong Ecological Construction" project and the "Park City" concept continue to integrate ecological construction, urban beautification, and social mobilization. The ongoing observance of Arbor Day, the expansion of multi-functional forest parks, and the systematic layout of street trees reflect the institutionalization of early concepts and systems in contemporary governance. Re-examining these historical experiences under the lens of sustainable planning also reveals important lessons. For instance, during rapid afforestation efforts, attention must be paid to ecological benefits, species diversity, long-term management, and social equity. Additionally, Fenzel's approach to establishing nurseries and forest farms (zoning, experimentation, and diversity assessment) can be seen as a pioneering practice of "evidence-based planning", offering insights for modern data-driven and feedback-optimized urban greening initiatives.

In summary, Guangdong's sustainable afforestation and urban greening efforts were not a mere replication of Western models, but rather a localization of foreign knowledge adapted to the local context. Due to the lack of existing historical records, this study does not provide a detailed account of the entire process of modern afforestation in Guangdong under Western influence. However, the author still attempts to take a holistic perspective, looking back at this history to help readers better understand the knowledge sources, developmental logic, and underlying principles of modern sustainable afforestation and urban greening in Guangdong. This also provides new insights for researching the modernization of China's forestry and urban greening sectors. At the same time, it highlights the importance of cross-border knowledge exchange in addressing global ecological issues.

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

Abbreviations

The following abbreviations are used in this manuscript:

CZ	Chaozhou
SG	Shaoguan
ZQ	Zhaoqing
HZ	Huizhou
DQ	Deqing
GZ	Guzngzhou
GD	Guangdong
SANSYU	The School of Agriculture at National Sun Yat-sen University
FMFFBM	The First Model Forest Farm at Baiyun Mountain

Appendix A

Table A1. Overview of the primary historical materials used in this study.

Year	Title	Source	Type
1917	Governor Zhu's advocacy of tree-planting commemoration	Guangdong Agriculture and Forestry Monthly	Journal
1917	On the Neglect of Forests and Suggestions for Their Recovery	Guangdong Agriculture and Forestry Monthly	Journal
1924	Encouraging everyone to plant trees.	Agricultural Monthly	Journal
1928	A Further Explanation for Those Planting Street Trees	Journal of the College of Agriculture of the National Central University	Journal
1929	Forest Service proceeds to draft forest regulations	Agricultural Voice	Journal
1929	What we should know about forests	Agricultural Monthly	Journal
1929	Tree Planting Ceremony in front of the Mausoleum	Republican Daily	Journal
1929	Guangzhou Municipal Forest Farm Began Setting Boundaries Yesterday	Guangzhou Municipal Gazette	Journal
1929–1930	Practical methods of afforestation work and nursery facilities in Guangdong		Book
1930	Importance of Forestry in Guangdong's Economic Development	Agricultural Voice	Journal
1931	The plan to establish seven major forest farms across Guangdong	Journal of the New Seedlings	Journal
1931	Report on the work of planting street trees on the Jiepu highway in the 19th year of the republic of China	Journal of the New Seedlings	Journal
1931	Overview of Nurseries in Chaozhou	Journal of the New Seedlings	Journal
1931	Guangdong Agriculture and Forestry	Agriculture and Forestry Bureau	Journal
1932	Pine Forest in Front of Baiyun Mountain	Zhejiang Provincial Construction Monthly	Journal
1932	Public Works Bureau Adds Pavilion in Zhongshan Park (Shipai)	Guangzhou Municipal Government Gazette	Journal
1932	Proposed Addition of Four-Eaved Pavilion in Zhongshan Park (Shipai)	Guangzhou Municipal Government Gazette	Journal
1932	Public Works Bureau Renovates Zhongshan Park	Guangzhou Municipal Government Gazette	Journal
1932	Tree Planting Achievements in Various Counties in Guangdong, 1931	Special Issue for the 7th Anniversary of Sun Yat-sen's Death	Journal
1934	The regulation of Shipai Zhongshan Park as a forest park	Nanhua Daily	Journal
1934	National Sun Yat-sen University's First Model Forest Farm	The Popular Illustrated Newspaper	Journal
1934	Preparation of Forest Park by the Ministry of Industry	Municipal Gazette	Journal

Table A1. *Cont.*

Year	Title	Source	Type
1934	Guangzhou's Parks	Commemorative Issue for New Government Office Completion	Journal
1934	Guangzhou Guide		Book
1935	Guangdong Provincial Government Builds Astronomical Observatory in Zhongshan Park (Shipai)	Liangyou (The Young Companion)	Journal
1935	National Sun Yat-sen University	Current status of National Sun Yat-sen University	Book
1935	Guangzhou Government Three-Year Policy Report		Book
1936	Statistical Data: Forestry—Provincial Afforestation Statistics (1933)	Ministry of Industry Monthly	Journal
1937	Various Sectors Planted 2000 Trees in Zhongshan Park	Central Daily	Journal
1937	Landscape Quarterly		Book

Notes

[1] Daoyang Ling was born in Baoan, Guangdong. He completed his Bachelor's and Master's degrees in Agriculture and Forestry at MIT and Yale University School of Forestry. After returning to China, he worked at the Guangdong Provincial Agriculture and Forestry Bureau, he published works such as "The Relationship between Forests and Drought", "The Relationship between Forests and the Country", "Afforestation and Livelihood", and "Reflections on Guangzhou's Street Trees and Parks".

[2] *The Principle of People's Livelihood* is one of Yat-sen Sun's *The Three Principles of the People*, the other two being "nationalism"and "democracy". *Principle of People's Livelihood* is Yat-sen Sun's "social revolution" program, the theme of which is to realize the modernization of China, the development of social economy, and to achieve the people's welfare.

[3] Gottlied Fenzel (1896–1936), a native of Nuremberg, Bavaria, Germany, graduated from the University of Munich. He came to China twice, in 1927 and 1933, to teach at the National Sun Yat-sen University and the Northwest College of Agriculture and Forestry, and served as an advisor to the Guangdong Provincial Government of the Republic of China, deputy director of the Guangdong Provincial Forestry Bureau, and director of the First Model Forest Farm at Baiyun Mountain. He has written books such as "The Practical Methods of Afforestation and Nursery Facilities in Guangdong", "The Importance of Afforestation in the Economic Development of Guangdong", "The Relationship between the Natural Environment and Forestry is Enough to Influence the Rural Economy of Guangdong", and "Participation of Guangdong Province in the Protection of Natural Forests and the Natural Forests in the Southern Part of Shixing", et al.

[4] Sen Lin (1868–1943) was born in Fujian. President of the National Government of the Republic of China. Although he did not study abroad in his early years, he was educated at the Peiyuan Academy run by the American Church and the Yinghua College founded by American missionaries McKinley and Wulinji. Afterwards, he traveled to Japan, America, and Canada to work with Dr. Yat-sen Sun on national issues. These experiences fostered Sen Lin's modern thinking and influenced his governance of Guangdong.

References

1. Gloaguen, T.; Gadal, S.; Kamičaitytė, J.; Zaleckis, K. Structural Evolution of the Coastal Landscape in Klaipėda Region, Lithuania: 125 Years of Political and Sociocultural Transformations. *Land* **2025**, *14*, 1356. [CrossRef]
2. Roudometof, V. In search of global sociology: A critical overview of competing research agendas. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 889. [CrossRef]
3. Peng, C. *Modernity Localization: The Modern Transformation of Lingnan Cities and Architecture*; Tongji University Press: Shanghai, China, 2012; p. 74.
4. Chen, Y.; Yao, Z. A preliminary study of the forestry legal system in Guangdong Province in Republican. *South China Today* **2008**, *4*, 205–207.
5. Chen, Z. The ecological consciousness and ecological protection of Hanjiang river watershed from the Qing dynasty to the republic of China (1644–1949). *J. Beijing For. Univ. (Soc. Sci.)* **2017**, *16*, 1–8. [CrossRef]
6. Marks, R. *Tigers Rice, Silk, and Silt: Environment and Economy in Late Imperial South China*; Cambridge University Press: Cambridge, MA, USA, 1998; p. 194.
7. Saito, O. Forest history and the Great Divergence: China, Japan, and the West compared. *J. Glob. Hist.* **2009**, *4*, 379–404. [CrossRef]
8. Xu, R. From Central Park to Greenway: A Review on the Construction of Public Green Space in Guangzhou for the Past Century. *Urban Insight* **2016**, *5*, 122–138.
9. Han, Y.; Li, B. Analysis of City Planning Practice of Guangzhou around the Period of Establishing its Municipal System. *Urban Plan. Forum* **2019**, *5*, 102–109.
10. Zou, D. Guangzhou Urban Planning and Construction in Chinese Republican Period. *Planners* **2017**, *33*, 142–146.

11. Sadakage, O.; Fan, B. Forestry. *J. Agric. Sci.* **1900**, *125*, 15–60.
12. Chi, X. Living from death: The modernization of mausoleum forest in Fengtian province in the early years of the republic of China. *Seek. Truth* **2020**, *47*, 171–180. [CrossRef]
13. Institute of Modern History Chinese Academy of Social Science. *The Complete Works of Sun Yat-sen*; Zhonghua Book Company: Beijing, China, 1981; Volume 1, p. 11.
14. Sun, Y. *Plans of National Reconstruction*; Guangdong People's Press: Guangzhou, China, 1996; p. 367.
15. Institute of Modern History Chinese Academy of Social Science. *The Complete Works of Sun Yat-sen*; Zhonghua Book Company: Beijing, China, 1986; Volume 9, pp. 407–408.
16. Fu, Z. The forest and the anti-japanese war during the extraordinary period. *J. Sichuan For.* **1938**, 20–27.
17. Huang, K. On the Neglect of Forests and Suggestions for Their Recovery (Continued 7). *Guangdong Agric. For. Mon.* **1916**, *2*, 1–10.
18. Huang, K. On the Neglect of Forests and Suggestions for Their Recovery (Continued). *Guangdong Agric. For. Mon.* **1916**, *1*, 5–15.
19. Chen, X. What we should know about forests. *Agric. Mon.* **1929**, *7*, 16–21.
20. Sun, K. Urban Planning Theory. *Construction* **1919**, *1*, 855–871.
21. Schmid, A. *Yesterday's Reflections: A Repository of Memories*; iUniverse: Lincoln, NE, USA, 2013; p. 39.
22. Wang, D.; Liang, S. Discourse construction of Chinese modernization from the perspective of Malaysian media. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 653. [CrossRef]
23. Governor Zhu's advocacy of tree-planting commemoration. *Guangdong Agric. For. Mon.* **1917**, *1*, 121.
24. Lipset, S. *Political Man: The Social Bases of Politics*; The Commercial Press: Beijing, China, 1986; p. 56.
25. Tree Planting Ceremony in front of the Mausoleum. *(Shanghai) Republican Daily*, 13 March 1929; p. 6.
26. Chen, Y. Arbor day and worship of Sun Yet-san. *J. Nanjing Univ. (Philos. Humanit. Soc. Sci.)* **2006**, *43*, 15.
27. Fenzel, G.; Qi, J. Importance of Forestry in Guangdong's Economic Development. *Agric. Voice* **1930**, *100*, 67–68.
28. Forest Service proceeds to draft forest regulations. *Agric. Voice* **1929**, *118*, 74.
29. National Sun Yat-sen University. *Current Status of National Sun Yat-sen University*; Department of National Sun Yat-sen University Press: Guangzhou, China, 1935; pp. 162–184.
30. Pine Forest in Front of Baiyun Mountain. *Zhejiang Prov. Constr. Mon.* **1932**, *5*, 1.
31. The plan to establish seven major forest farms across Guangdong. *J. New Seedl.* **1931**, *2*, 21–22.
32. Nai, M. Overview of Nurseries in Chaozhou. *J. New Seedl.* **1931**, *2*, 28.
33. Fenzel, G.; Qi, J. *Practical Methods of Afforestation Work and Nursery Facilities in Guangdong*; National Sun Yat-sen University Press: Guangzhou, China, 1929; p. 5.
34. Tang, J. My Opinion on Cultivating City Street Trees. *Munic. Rev.* **1936**, *3*, 23–24.
35. Kunstler, J. *The City in Mind: Notes on the Urban Condition*; Simon and Schuster: New York, NY, USA, 2003; pp. 21–26.
36. Xu, Q. Road beauty. *Road Mon.* **1929**, *28*, 30–32.
37. Lin, S. Encouraging everyone to plant trees. *Agric. Mon.* **1924**, *2*, 8–10.
38. Wang, F. Report on the work of planting street trees on the Jiepu highway in the 19th year of the Republic of China. *J. New Seedl.* **1931**, 76–77.
39. Hopkins, R., Jr. *Engineering Nature: Public Green Spaces in Nineteenth-Century Paris*; Arizona State University: Phoenix, AZ, USA, 2023.
40. Emge, D.; Kleespies, M.; Wenzel, V. Measuring attitudes towards historic gardens: Development and validation of the Garden Heritage Scale. *Humanit. Soc. Sci. Commun.* **2024**, *11*, 911. [CrossRef]
41. Shirakawa, Y. *A History of Modern Urban Parks*; New Star Press: Beijing, China, 2014; p. 92.
42. Gao, C. A Discussion on Forest Parks. *Chin. Landsc. Archit.* **1997**, *6*, 7–8.
43. Kong, X. For the provincial capitals should be prepared to set up forest parks. *Ind. Bull.* **1931**, *26*, 23.
44. Public Works Bureau Adds Pavilion in Zhongshan Park (Shipai). *Guangzhou Munic. Gaz.* **1932**, *403*, 52.
45. Proposed Addition of Four-Eaved Pavilion in Zhongshan Park (Shipai). *Guangzhou Munic. Gaz.* **1932**, *406*, 88–89.
46. Public Works Bureau Renovates Zhongshan Park. *Guangzhou Munic. Gaz.* **1932**, *407*, 63.
47. Guangdong Provincial Government Builds Astronomical Observatory in Zhongshan Park (Shipai). *The Young Companion*, 1935; p. 103.
48. The regulation of Shipai Zhongshan Park as a forest park. *Nanhua Daily*, 18 December 1934.
49. Guangdong Agriculture and Forestry. *Agriculture and Forestry Bureau*; Guangdong Provincial Department of Construction: Guangzhou, China, 1931; p. 345.
50. Various Sectors Planted 2,000 Trees in Zhongshan Park. *Central Daily News*, 21 February 1937.

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