Research on Strategies for Enhancing Urban Spatial Resilience in Shanghai Based on the Connotations and Characteristics of "Resilient Cities"

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Abstract: This paper explores the enhancement strategies for urban spatial resilience in Shanghai by defining, interpreting, and identifying the characteristics of "urban spatial resilience." Firstly, it analyses the relationship between resilient cities and urban spatial resilience. Secondly, it examines the systemic composition, organisational methods, and representation of resilient cities, revealing three essential contents—hierarchical structures, resilience mechanisms, and resilience representations—and four fundamental characteristics (13 attributes): capacity, structure, mechanism, and representation. Thirdly, it reviews the urban spatial planning, spatial expansion changes, and urban compactness variations in Shanghai since 1985. Finally, the paper identifies current issues in Shanghai's urban spatial development and proposes strategies to enhance its urban spatial resilience.

Keywords: Resilient Cities, Spatial Resilience, Shanghai, Construction Principles, Enhancement Strategies

1. Introduction

Urban areas today face many crises and challenges, including global warming, increased extreme weather events, and urban flooding, which render urban systems vulnerable and susceptible to disturbances. Since the inception of the "resilient city" concept, it has emerged as a new paradigm for addressing urban risks and uncertainties, garnering sustained interest from both the academic and political realms (Sharifi, 2019). Resilience thinking posits that cities are self-regulating complex systems (Holling et al., 2002), with resilient cities serving as tools to cope with uncertainty. Constructing resilient cities or enhancing urban resilience has become crucial for cities to face various challenges and achieve long-term sustainable development (UNDRR, 2013). This understanding has gradually evolved into a global consensus. The theory of resilient cities views urban areas as open, complex mega-systems, offering significant scientific guidance for urban planning and construction practices aimed at protecting the lives and properties of residents and enhancing urban functionality.

Since 2016, Shanghai has issued a series of policy documents aimed at enhancing urban spatial resilience, such as the "RISE" Vision Goals Framework for Shanghai's Urban Development over the Next 30 Years (2016), the Shanghai City Master Plan (2017-2035) (2018), and the Shanghai Urban Operation and Safety Development Report (2019-2020) Blue Book (2021). These documents repeatedly emphasise the importance of strengthening resilient city construction and achieving compact urban development and propose that by 2035, Shanghai will be fundamentally established as a "resilient city" capable of addressing various developmental risks and swiftly recovering from them. To counter issues such as continuous urban sprawl, population concentration in central urban areas, and the slow development of new cities, Shanghai advocates for a compact metropolitan spatial pattern and a transition from extensive expansion to baseline constraint and intrinsic development (Shaobo et al., 2019).

Thus, constructing resilient cities and enhancing urban spatial resilience are among the critical planning objectives for current urban development in Shanghai.

Urban spatial resilience has emerged within the development and evolution of resilience, resilient cities, and urban resilience. Therefore, it is necessary to delineate and clarify the relationships among resilience, resilient cities, urban resilience, and urban spatial resilience. This paper is based on analysing the concepts, contents, and characteristics of resilience, resilient cities, urban resilience, and urban spatial resilience. It proposes a theoretical model for urban spatial resilience and examines the development trajectory, current issues, construction principles, and urban spatial resilience enhancement strategies in Shanghai. The research conclusions presented here are intended to deepen the understanding of urban spatial resilience among city managers and researchers. This deeper understanding facilitates a more thorough grasp of the concepts, contents, and characteristics essential for building resilient cities, providing valuable insights and references for urban development strategies.

2. Definitions, Connotations, and Characteristics of Resilient Cities

2.1 The Concept and Evolution of Resilient Cities

The concept of "resilience" has been extensively applied across multiple disciplinary fields such as engineering, psychology, disaster studies, economics, management, social sciences, and environmental science. Although descriptions of "resilience" vary among disciplines, they all emphasise its characteristics related to absorption, resistance, maintenance, self-organisation, adaptation, learning, and transformation. Following the perspective of Professor Shen Qingji, this paper defines "resilience" as the capacity of a system to maintain or restore its necessary functions in the face of disturbances, adapt to changes, and swiftly transform when its adaptive capacity is constrained.

Similar to other fields, the concepts of "Urban Resilience" and "Resilient City" emerged when applied to urban systems. The term "Resilient City" was first introduced by Local Governments for Sustainability (ICLEI) during the 2002 United Nations Summit on Sustainable Development. It emphasised a systemic construction process combining material aspects such as engineering improvements and facility enhancements with social dimensions, including public participation and institutional innovation, to enhance the overall resilience of urban systems. While there is no unified definition of a resilient city within the academic community to date, there is a consensus on its connotation and value: a resilient city possesses diverse disaster adaptation capabilities. Research varies from focusing on urban stability reconfiguration under environmental impacts, highlighting the rapid adaptive system characteristics of cities, to emphasising the adaptive capacity of cities and their residents to risks, yet all converge on the core notions of "stability," "resistance," and "adaptability." By analysing the interrelations among resilience, resilient cities, urban resilience, and urban spatial resilience, this paper further explicates the definition of a resilient city as a type of advanced urban form that possesses strong adaptive and learning capacities, effectively responds to significant urban disturbances such as climate change threats, ecological issues, public health incidents within a particular spatiotemporal scope, promptly restores structural and functional stability, and continues to evolve beneficially.

This paper classifies international research on resilient cities into four stages: nascent, initial, rapid, and reflection continued development (Figure 1). From the perspective of evolutionary trends, early research on resilient cities focused on human psychological resilience and

ecosystem resilience, gradually transitioning to diverse studies targeting different components and processes within urban socio-ecological systems. The scope of the inquiry has shifted from initially addressing common natural disasters and risks to increasingly dealing with emerging urban environmental and social issues, as well as derivative problems, thereby deepening integration with the discipline of urban planning.

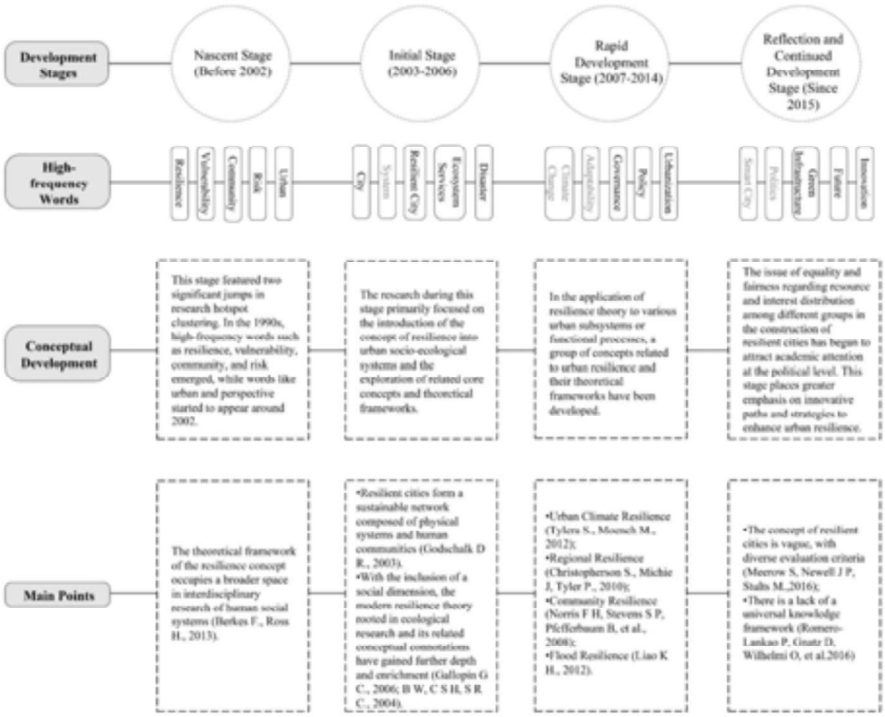

Figure 1: Evolutionary Stages of the "Resilient City" Concept

2.2 The Connotations of Resilient Cities

Based on an examination and analysis of the existing literature on "resilience," "urban resilience," and "resilient cities," this paper categorises the intrinsic connotations of resilient cities into three core components: hierarchical structures, resilience mechanisms, and resilience representations, covering the systemic composition, organisational methods, and representational forms of resilient cities (Figure 2).

Figure 2: Diagrammatic Representation of the Information Structure of Resilient Cities

(1) **Hierarchical Structure:** Refers to the stable structure formed by resilient cities' subsystems, system levels, and system elements under specific mechanisms. It represents resilient cities as complex systems.

(2) **Resilience Mechanisms:** Historical experiences indicate that urban development is long influenced and constrained by natural environments and human will, gradually evolving capabilities that maintain urban functions and structures and foster benign urban development. These capabilities are manifest in adaptive and learning abilities. The operational mechanisms of resilient cities serve as the analytical basis for examining the logical connections between their hierarchical structures and resilience representations. In integrating urban components and influencing factors, four resilience mechanisms have emerged to maintain urban structural stability—stability, sensitivity, resistance, and recovery—based on the two capability features (system organisational rules).

(3) **Resilience Representations**: From a psychological perspective, representation refers to the method by which segments of world information stored in the human mind are depicted or described, as well as how objects exist within individual psychology. Representation theory elucidates the connections between the representational information of objects and their physical or non-physical forms, linking information with people’s perceptions of specific objects or events (Distin, 2005).

The representational forms of "resilient cities" are meant to express their intrinsic meanings, consisting of tangible and intangible urban characteristics. This study categorises the core connotations of "resilient cities" into four aspects based on urban components' material and non-material properties: urban spatial resilience, urban ecological resilience, urban social resilience, and urban economic resilience. These four cores are represented in different cities in varying proportions, resulting in distinctive, resilient city representations, including healthy, safe, resilient, low-carbon, ecological, and innovative resilient cities. Due to resilience

mechanisms being inherent attributes of all types of resilient cities, it is recommended to use "urban scale," "urban structure," "urban elements," and "resilience representations" as criteria for analysing city types. The classification of resilient city types should be based on assessments of their "complexity" and "connotative representations," and these criteria should be used in case studies to determine the specific type of resilient city.

(1) Based on evaluations of urban hierarchy, connectivity, and the number and types of urban elements, definitions of resilient city complexity are delineated as "ultra-high complexity (C1), high complexity (C2), medium complexity (C3), and low complexity (C4)."

(2) An evaluation system for resilient cities covering spatial resilience, ecological resilience, social resilience, and economic resilience is established. Definitions for the representational forms of resilient cities, such as health resilience, safety resilience, low-carbon resilience, ecological resilience, and intelligent resilience, are derived based on evaluation scores. In case studies, the most representative form of resilience representation can be selected as a keyword to determine the specific type of a city.

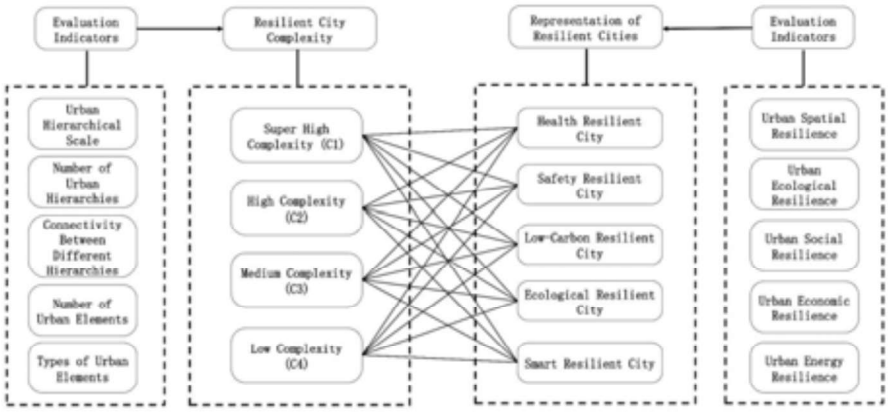

Figure 3: Classification of Resilient Cities

As shown in Figure 3, based on the results of evaluating the "complexity" and "connotative representations" of resilient cities in case studies, a combination of keywords from both categories yields 20 types of resilient cities across 4 complexity levels and 5 representational forms:

2.3 Characteristics of Resilient Cities

The characteristics of resilient cities are an extended expression of their concept and core connotations. This paper categorises the characteristics of resilient cities into four types with thirteen essential attributes (Table 1): capability characteristics, structural characteristics, mechanism characteristics, and representational characteristics.

(1) Capability Characteristics of resilient cities include adaptability and learning ability, which are the fundamental reasons behind the formation of resilience mechanisms in resilient cities.

(2) Structural and Elemental Characteristics refer to the system hierarchical structures formed under the influence of resilience mechanisms and the type and number of constituent elements of resilient cities.

(3) Mechanism Characteristics comprise stability, sensitivity, resistance, recovery, and resource redundancy. These are the system mechanisms that maintain resilient cities' functional and structural stability.

(4) Representational Characteristics include health resilience, safety resilience, low-carbon resilience, ecological resilience, and intelligent resilience. These human cognitive expressions abstract the capabilities, structures, and mechanisms of resilient cities into the most representative features.

Table 1: Classification and Analysis of Resilient City Characteristics

Characteristic Type	Characteristic Name	Characteristic Analysis
Capability Characteristics	Adaptive capacity Learning Ability	Based on historical experience, it is known that urban development is long influenced and constrained by natural environments and human will, gradually generating the ability to maintain urban functions and structures and promote benign urban development. It manifests as two capability characteristics: adaptability and learning ability.
Structural Characteristics	Hierarchical Features Elemental Features	As complex systems, cities' structural characteristics are inherent reflections of their functions and operational mechanisms. The structural features of resilient cities demonstrate the tangible or intangible urban hierarchical structures formed under the influence of resilience mechanisms, reflecting the core connotations of urban space, ecology, society, and economy and their energy and material flow characteristics.
Mechanism Characteristics	Stability Sensitivity Resistance Recovery	The operational mechanisms of resilient cities serve as the analytical basis for examining the logical connections between their hierarchical structures and resilience representations. Based on the two capability features in the integration process of urban components and influencing factors, four resilience mechanisms have emerged to maintain urban structural stability: stability, sensitivity, resistance, and recovery.
Representational Characteristics	Health Resilience	Representation theory elucidates the connections between the representational information of objects and their physical or non-physical forms, linking information with people's perceptions of specific objects or events (Distin, 2005). The representational characteristics of resilient cities are meant to express their most representative and abstracted urban features clearly.

3. Developing a Theoretical Model of Urban Spatial Resilience Based on the Connotations and Characteristics of Resilient Cities

Incorporating the definitions, connotations, and characteristics of resilience, resilient cities, urban resilience, and urban spatial resilience, this paper constructs a theoretical model for urban spatial resilience.

3.1 Urban Resilience and Urban Spatial Resilience

Urban "resilience" constitutes the core connotation of "resilient cities." Research from various countries indicates that the core information of urban "resilience" includes the constituent elements under hierarchical states, the reduction (or resistance) of disaster types, and the maintenance (or restoration) of a stable state, as well as adaptability to uncertain urban issues. Based on these core elements of urban "resilience" (Figure 4), this paper defines urban "resilience" from the perspectives of resilience capacity and system structure. Urban "resilience" is described as an inherent property of the city, manifested through a hierarchical structure organised from the bottom up by urban components. It exhibits stable characteristics that enable the city to maintain stability through rapid response capabilities, recovery capabilities in the event of sudden incidents, defence capabilities against similar events, and adaptability (or optimisation) capabilities.

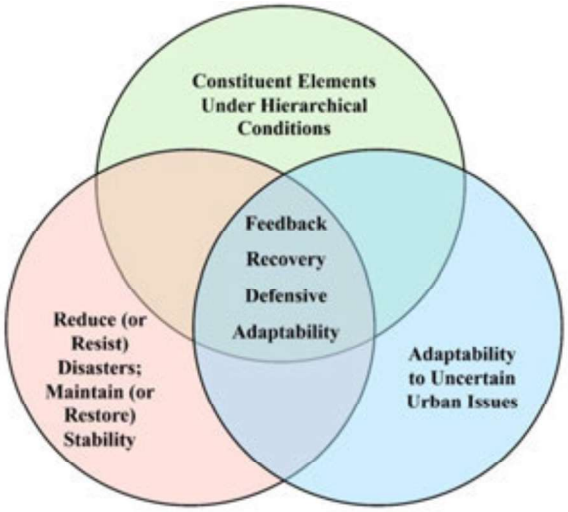

Figure 4: Core Information on Urban "Resilience"

This paper interprets urban spatial resilience as a subset of urban resilience, emphasising the state of resilience within the spatial dimension. The principal subject of the urban spatial resilience concept is urban space, with a focus on spatial attributes, representing the capacity for continuous development and operation of the urban spatial system. This capacity includes the ability to withstand disaster risks, absorb external shocks, and quickly recover essential functions. Resilient urban spaces can help maintain the integrity of urban system functionalities.

Urban spatial resilience is characterised by integrating the three elements of urban space: "scale, density, and form." Urban scale is evaluated based on ecological infrastructure and landscape safety patterns; urban density is assessed through ecological footprint and carrying capacity evaluations; urban form is measured using the "source-sink" landscape mean distance index (Xiu et al., 2018). Enhancing urban spatial resilience involves establishing redundant critical infrastructures, stable open spatial patterns, and modular, scalable spatial units across macro, meso, and micro urban scales to ensure sustainable urban development. Numerous researchers have explored urban spatial resilience from various perspectives. For instance, Liu (2014) defined "resilience planning" as the coordinated integration of rigid and flexible planning to maximise planning efficacy and defined morphological resilience as the characteristic of a spatial form that can sustain spatial development goals while fully accommodating diverse spatial usage demands (K. Liu, 2014). "Morphological resilience" planning techniques determine the material spatial elements that need rigid control according to spatial planning goals, using these rigid elements as the essential components of the spatial structure. Applying open, modular resilience planning techniques constructs an overall spatial structure closely linked with the spatial connotations of urban resilience. Famous urban models such as organic evacuation, cluster, and grid cities exemplify spatial resilience, characterised by stable, open spatial frameworks and modular, scalable spatial units. Xiu, Wei, and Wang (2018) developed a three-dimensional urban resilience research framework based on "scale—density—form" with clear spatial connotations (Xiu et al., 2018). In this framework, urban scale is evaluated based on ecological infrastructure and urban landscape safety patterns; urban density is assessed through ecological footprint and carrying capacity; urban form is evaluated using the "source-sink" landscape mean distance index. Shi (2016), using Shanghai as an example, explored the spatial requirements for enhancing resilience in mega-cities: (1) ensuring a safety baseline with life circles as the basic unit; (2) building disaster prevention systems with urban clusters as network groups; (3) coordinating the overall disaster prevention layout within the municipal area; (4) establishing regional strategic cooperation platforms (Shi, 2016).

This paper proposes that understanding urban spatial resilience should be approached from three critical perspectives:

(1) Transformation of Urban Spatial Resilience into Spatial Resilience Features: It is suggested to cognise and express "urban spatial resilience" as "spatial resilience features". It can be achieved by adopting a series of landscape indices from landscape ecology and representing the spatial resilience of different urban areas through a "Resilience Spatial Distribution Map".

(2) Relationship between Urban Spatial Resilience and Environmental Factors: Urban spatial resilience is closely linked to the natural environment, geological setting, hydrological conditions, wind environment, built environment, and spatial infrastructure factors of the city's location. Urban spatial resilience can be enhanced by expanding the spatial area under consideration.

(3) In-depth and Multi-dimensional Analysis of Urban Spatial Resilience: Efforts should be made to conduct a thorough and multifaceted analysis of urban spatial resilience. It could involve dividing urban areas into resilient and non-resilient spaces, resilient and non-resilient functions, and resilient and non-resilient structures.

3.2 Resilience" Theoretical Model

Based on the definition of "resilience," this paper establishes a "resilience" theoretical model based on its core information (Figure 5). The model specifies and describes the essential elements, operational characteristics, core information, and operational rules of the "resilience" theoretical model.

(1) Basic Elements: Includes both material entities and abstract objects.

(2) Operational Characteristics (Constraints): The "resilience" model is characterised by seven features during operation: "absorption," "resistance," "maintenance," "self-organisation," "adaptation," "learning," and "transformation."

(3) Core Information: The seven operational characteristics are simplified and categorised into four types of information, namely "recovery capability," "maintenance capability," "adaptability," and "transformation capability."

(4) Operational Rules (Also Known as Principles): These rules dictate how combinations of essential elements can form connections that represent the operational characteristics and core information of "resilience."

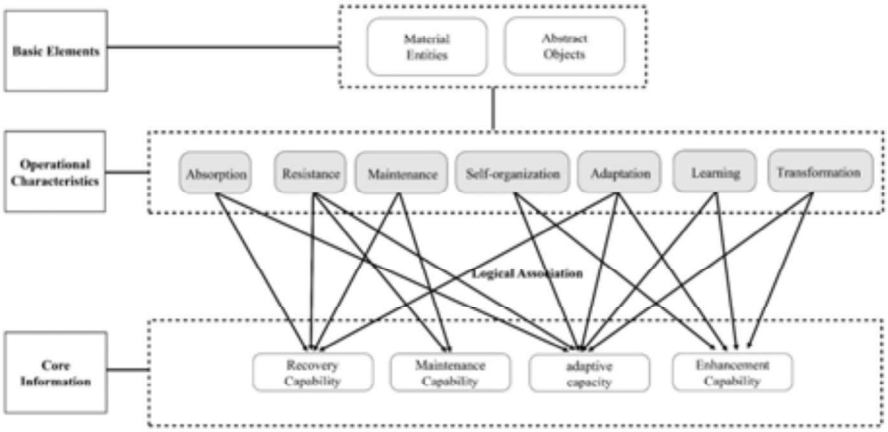

Figure 5: Theoretical Model of "Resilience"

3.3 Theoretical Model of Urban Spatial Resilience

Resilient cities are complex dynamic systems where closely interconnected subsystems create complex interactions that reflect the city’s political, economic, and social relationships. Therefore, resilient cities can be analysed through the relationships among subsystems and system elements (Yang M. et al., 2016; Zhou & Yuan, 2017). The urban spatial structure manifests the results of interactions among hierarchical structures, functions, and elements.

This study initially categorises urban spatial resilience into three systemic levels: macro, meso, and micro. Based on the physical and non-physical scale of system constituent elements, the meso and micro levels can be further subdivided, resulting in a hierarchical structure of single macro, multiple meso, and multiple micro levels (Figure 6).

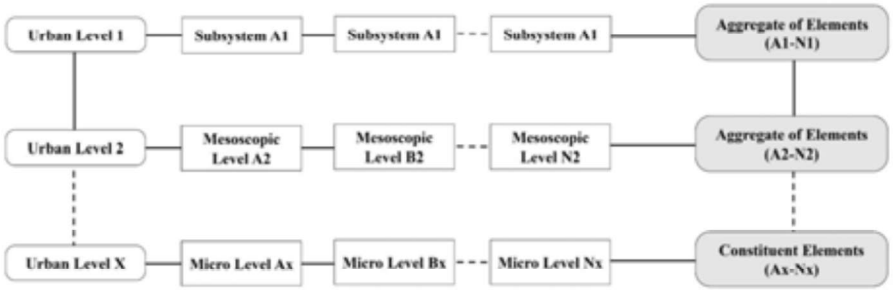

Figure 6: Schematic of Urban Spatial Hierarchical Structure

Based on the "resilience" theoretical model and the connotations and characteristics of resilient cities, this paper further proposes a theoretical model of "urban spatial resilience" (Figure 7). This model comprises operational mechanisms, influencing factors, hierarchical structures, organisational rules, intrinsic connotations and representational forms, and system capabilities.

(1) Operating Mechanisms: Adaptability and learning ability are the core operating mechanisms for urban spatial resilience. Individual cities and urban clusters optimise and reorganise their spatial resilience systems spontaneously by adapting to and learning from the impacts affecting their urban spatial resilience.

(2) Influencing Factors: These include a variety of factors such as the urban ecological environment, socio-economic factors, urban transportation, and land use. The operating mechanisms of the urban spatial resilience system are generated through adaptation to and learning from these factors affecting urban resilience spaces.

(3) Hierarchical Structure: The material and non-material essential components of cities form a stable hierarchical structure under the influence of two resilience mechanisms. From both physical and logical scales, this involves organising resilience components of urban spaces from the bottom up, forming a hierarchical structure with resilience and stability characteristics consisting of a single macro-level, multiple subsystems, multiple meso-levels, and multiple micro-levels, with individual forms varying based on specific case studies.

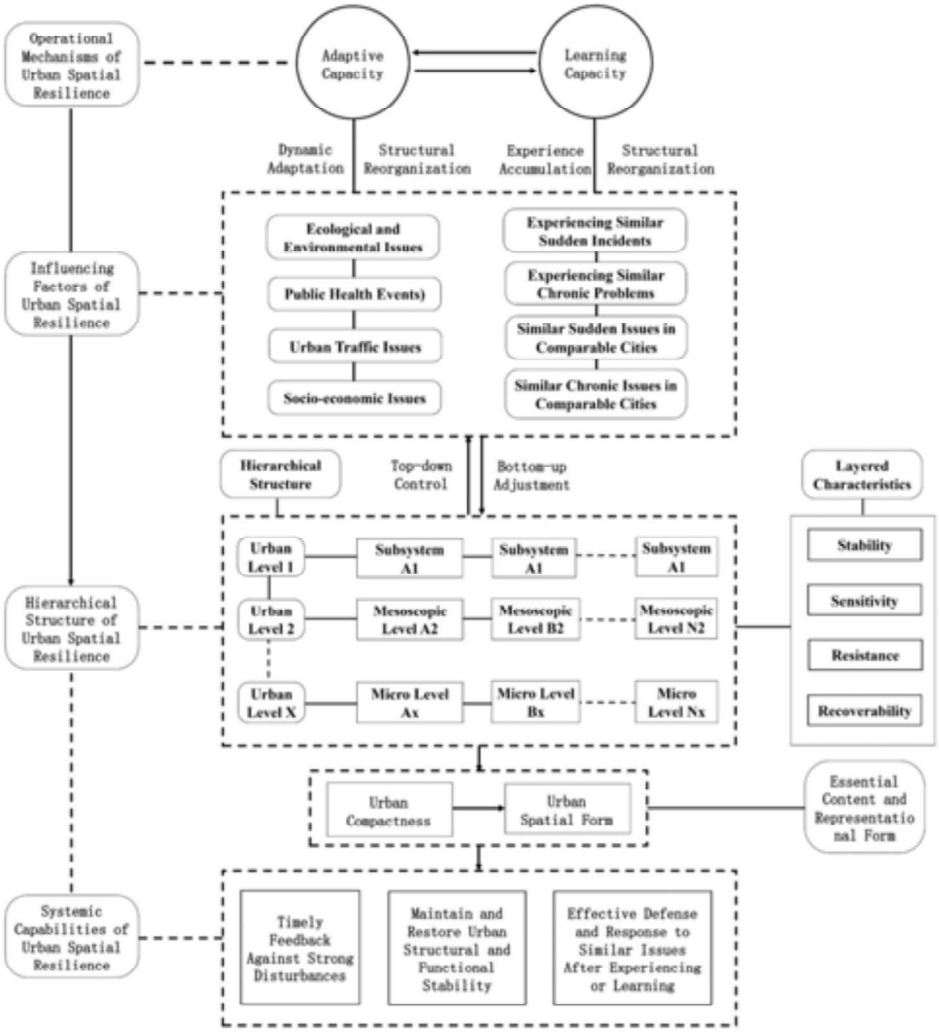

Figure 7: Theoretical Model of Urban Spatial Resilience

(4) Organisational Rules: Stability, sensitivity, resistance, and recovery serve as the organisational rules for urban spatial resilience at different hierarchical levels, forming a relatively stable structure at the system-wide level that can achieve and maintain specific functions. This stable structure can be continuously optimised through adaptation and learning concerning the types, quantities, and connections of the elements composing the different levels of urban spatial resilience.

(5) Intrinsic Connotations and Representational Forms: Urban compactness is the intrinsic connotation of urban spatial resilience, involving the economical and intensive use of land

resources, centralised layout of urban functional elements, enhanced management of urban spatial growth, promotion of high density and mixed-use of urban land, and strengthened urban planning management. The representational form of urban compactness is the urban spatial form.

(6) System Capabilities: Based on the influencing factors of urban spatial resilience, the operating mechanisms effectively organise the hierarchical structure of urban spatial resilience, fostering the generation of three system capability features of urban spatial resilience: "timely feedback against strong disturbances," "maintenance and recovery of urban structure and functional stability," and "effective defence and response to similar issues after experiencing or learning."

4. Shanghai Urban Spatial Resilience: Development Trajectory, Current Issues, and Enhancement Strategies

4.1 Urban Spatial Planning in Shanghai Since 1985

Shanghai's urban planning can be traced back to the "Greater Shanghai Plan" of 1929 (Figure 8), inspired by Ebenezer Howard's "Garden Cities of To-morrow" (1902). This plan employed a grid layout and designated a city centre in Yangpu district, encompassing government buildings, museums, and other public amenities. Although the onset of war in 1937 halted its implementation, this plan laid the foundational principles for subsequent urban planning (MacPherson, 1990). Post-war, multiple master plans were drafted, notably in 1946 and 1956, emphasising industrial development and population decentralisation to alleviate congestion in the central areas(Shanghai Local Chronicles Office, 2003). After the establishment of the People's Republic of China, Shanghai's planning ideology transitioned into the era of Soviet Planning Theory, focusing on industrial orientation and residential environment improvements (Soviet Planning Theory 1949-1958 · Shanghai: Urban Design and Planning, 2024). The 1959 plan significantly expanded Shanghai's administrative boundaries and envisioned transforming Shanghai into a leading beautiful city (Shanghai Urban Master Plan 1959 Edition, 2024). From 1984 onwards, Shanghai pivoted towards becoming a multifunctional economic hub. The 1986 plan further solidified Shanghai's status as a major international metropolis (The State Council’s Response to the Master Urban Planning Scheme for Shanghai, 1986). The plans from 1999 to 2001 established an urban spatial structure that facilitated harmonious development across various urban levels. The latest master plan (2017-2035) projects a longer-term vision, aiming to position Shanghai as a globally influential centre of technological innovation and a modernised international metropolis by 2035, introducing a spatial configuration of "one core, two axes, four wings; multiple corridors, multiple cores, multiple circles".

Figure 8 History of urban planning development in Shanghai

4.2 Urban Spatial Expansion in Shanghai Since 1985

To further analyse the urban spatial expansion of Shanghai since 1985, this study leverages data from (J. Yang & Huang, 2021), which utilises 335,709 Landsat images available on the Google Earth Engine. The methodology involves collecting training samples by combining stable samples extracted from the China Land Use/Cover Dataset (CLUD) with visual interpretation samples from satellite time series data, Google Earth, and Google Maps. The study employs multiple temporal indicators constructed from all available Landsat data, which are then input into a random forest classifier to obtain classification results, culminating in creating the China Annual Land Cover Dataset (CLCD) from 1985 onwards.

The results indicate that from 1985 to 2022, Shanghai's urban expansion predominantly exhibited a pattern of central aggregation and peripheral dispersion (Figure 9). This pattern reflects that the city's development extended beyond merely refilling old urban areas, expanding into peripheral regions and new districts. From 1985 to 1990, urban expansion was primarily concentrated in the city centre with minimal outlying growth. During this period, development focused on maximising the use of internal space and reconstructing key areas to accommodate the city's growing population and economic demands. Between 1990 and 2000, as the economy rapidly developed and urban policies adjusted, Shanghai's urban expansion began transitioning from the city centre to peripheral areas. The construction of major transport routes and new development zones catalysed swift expansion at the city's edges. After 2000, urban expansion entered a new peak period, reaching a nearly 40-year high, with the city centre area almost entirely urbanised. This trend continued until 2015. After 2015, urban growth began to slow, with expansion shifting towards suburbs and emerging satellite towns, characterised by "finger-like" growth patterns along major roadways and transit lines. By 2020, Shanghai's urban spatial expansion significantly slowed, indicating a transition into a more mature and stable development phase. The new urban development strategy emphasises ecological protection and sustainable development, aiming to improve residents' quality of life and environmental conditions while ensuring economic growth (Table 2, Table. 3).

Table 2 Changes in the area of built-up areas in Shanghai

Year	downtown area	Average annual growth	Extended strength	extension type
1985	631.45	/	/	/
1990	710.99	79.54	12.60	low speed
1995	1001.13	290.15	40.81	high speed
2000	1291.56	290.43	29.01	high speed
2005	1739.44	447.88	34.68	high speed
2010	2143.33	403.89	23.22	medium speed
2015	2355.34	212.00	9.89	low speed
2020	2489.10	133.77	5.68	low speed
2022	2537.84	48.74	1.96	low speed

Table 3 Changes in the area of downtown areas of Shanghai

Year	downtown area	Average annual growth	Extended strength	extension type
1985	358.90	/	/	
1990	416.95	58.05	16.17	low speed
1995	603.61	186.66	44.77	high speed
2000	788.56	184.95	30.64	high speed
2005	1029.50	240.94	30.55	high speed
2010	1374.12	344.62	33.47	high speed
2015	1483.85	109.74	7.99	low speed
2020	1545.64	61.79	4.16	low speed
2022	1568.33	22.69	1.47	low speed

Since 1985, Shanghai's urban area has expanded from 631.45 square kilometres to 2537.84 square kilometres in 2022, nearly quadrupling (Table 2). The pace of urban expansion has varied, generally following a 'reverse U' trend with initially slow, then rapid, and subsequently slowing growth rates. Between 1985 and 1990, urban expansion was relatively slow, focusing primarily on infilling the city centre and enhancing infrastructure. Since 1995, changes in domestic and international economic conditions and adjustments in urban policies have marked the beginning of a rapid development phase for Shanghai’s urban space. During this period, large-scale developments in suburbs and new districts significantly accelerated the pace of urban expansion, with annual expansion reaching nearly 30 square kilometres. This rapid expansion continued until 2010. After that, as the availability of suitable land for development decreased and urban planning policies shifted, the pace of Shanghai's urban expansion began to slow. The focus of urban development shifted from quantity to quality, emphasising improvements in the urban living environment and economic efficiency. Since then, the rate of urban expansion has stabilised at about 10 square kilometres per year.

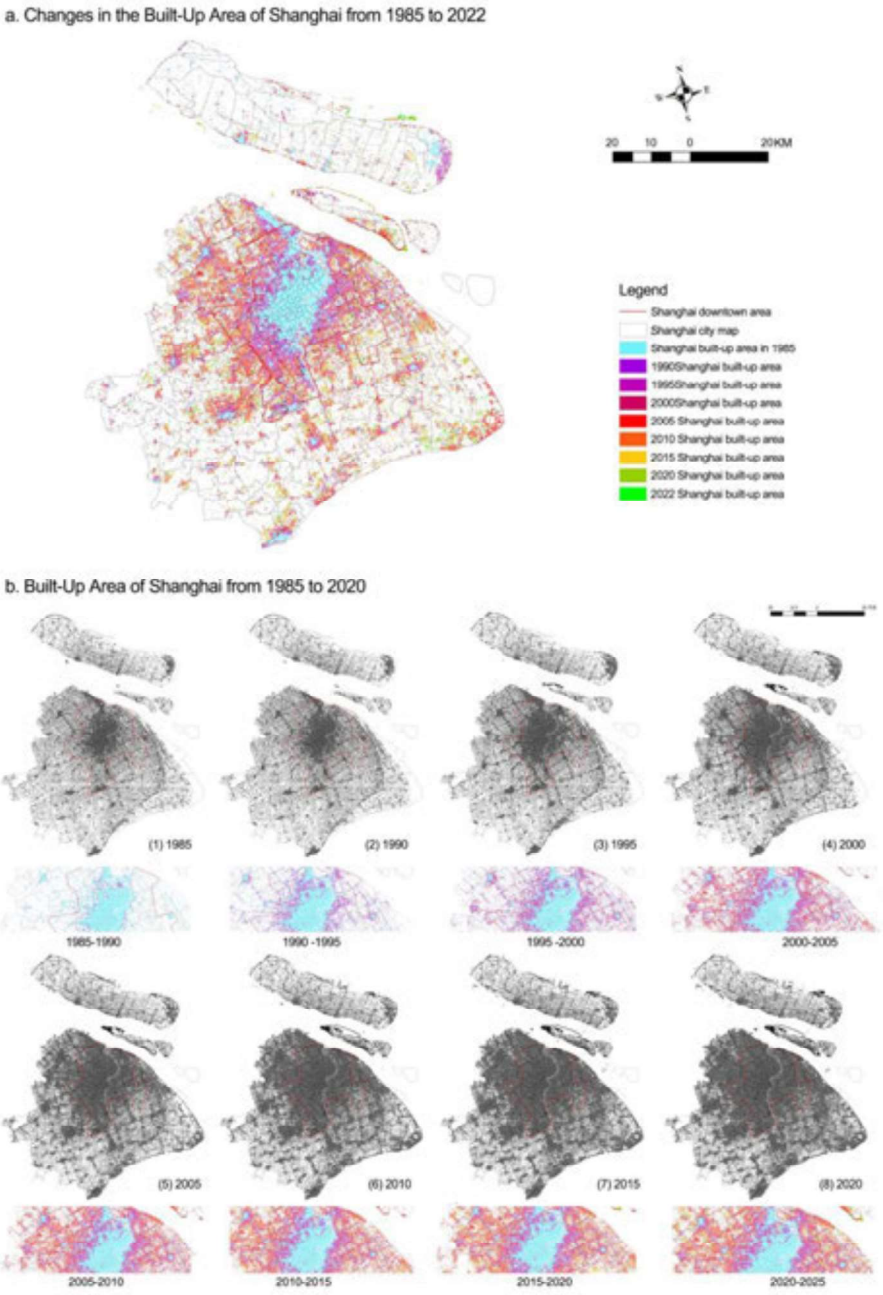

Figure 9 Changes in Shanghai's built-up area from 1985 to 2022

Since 2022, the pace of urban expansion in Shanghai has stabilised, indicating that the amount of land available for urban use in the city centre is nearing saturation. Urban development is increasingly focused on enhancing the efficiency of existing urban land use and improving the quality of urban life. The government and developers are actively seeking new urban development models, such as through urban renewal and the transformation of old districts to optimise urban spatial configuration and enhance city functions while also strengthening the construction of green infrastructure and public service facilities to support a sustainable urban future.

4.3 Current Issues in Shanghai's Urban Spatial Resilience Construction

The challenges posed by climate change and rapid urbanisation are particularly pronounced in the construction of urban spatial resilience in Shanghai. As global warming intensifies, Shanghai is increasingly subjected to extreme weather events such as floods and high temperatures. While significant progress has been made in enhancing flood defences, the measures in place to cope with high temperatures remain inadequate, especially regarding disaster monitoring and early warning systems that require further strengthening. Rapid urban expansion has exerted substantial pressure on the ecological environment, leading to a reduction in urban green spaces and wetlands and a decline in ecosystem functions. Reducing natural buffer zones and ecological barriers increases the city's vulnerability to natural disasters.

Moreover, the city's economic resilience is also being tested. Although Shanghai has become a central global commercial and financial hub, its economy is highly dependent on international markets and foreign investment, which may pose challenges during global economic instability. Additionally, Shanghai is continuously focusing on enhancing social resilience. City administrators are striving to improve public health services, the education system, and housing policies to enhance the quality of life for residents. Nevertheless, rapid urbanisation continues to cause uneven distribution of resources and social stratification. Urban planners and policymakers in Shanghai need to consider these complex factors to develop more effective strategies that promote sustainable development and strengthen urban resilience.

4.4 Analysis of the Relationship Between Urban Compactness and Urban Spatial Resilience

Urban compactness typically refers to a city's intensive and efficient spatial arrangement, encompassing high-density construction, multifunctional land use, and effective public transportation systems (Dantzig & Saaty, 1973; Lan et al., 2021). Urban spatial resilience, however, focuses on a city's ability to maintain critical functions, rapidly recover, and adapt to natural disasters, economic crises, or social changes. Both concepts are crucial topics in the field of sustainable urban development. These principles aim to enhance urban environments' liveability, sustainability, and adaptability, ensuring that cities can withstand and adapt to various challenges while continuing to thrive.

According to relevant theories of urban economics, Richardson et al. proved that the most efficient external space form of urban construction is circular. When the city is round, the compactness is 1. The larger the Richardson index, the more compact the spatial shape. This paper refers to relevant studies (Lan et al., 2021; Lv et al., 2022; Meng & Xing, 2019) and uses Richardson index to express the compactness of the block. Moreover, it is calculated as follows:

$$C = \frac{2\sqrt{\pi * A}}{P}$$

Where A is the area of the block, P is the block's perimeter.

The changes in the compactness of Shanghai city are shown in Figure 10. From 1990 to 2005, the increase in compactness was relatively stable, with an increment of approximately 0.02 every five years. It likely reflects the orderly advancement of urban planning and infrastructure development in Shanghai during this period, gradually enhancing the efficiency of urban operations and the quality of life for residents. The growth in compactness significantly accelerated between 2005 and 2010, increasing by 0.05. This change may be associated with accelerating urbanisation in Shanghai, such as hosting the 2010 Shanghai Expo. Much infrastructure construction and urban expansion likely occurred during this period. From 2010 to 2022, the growth in compactness returned to a stable state, with an increase of 0.01 every five years or two years. It indicates that urban development has entered a more mature and stable phase, where the optimisation and adjustment of urban space are more focused on details and quality, gradually enhancing urban spatial resilience.

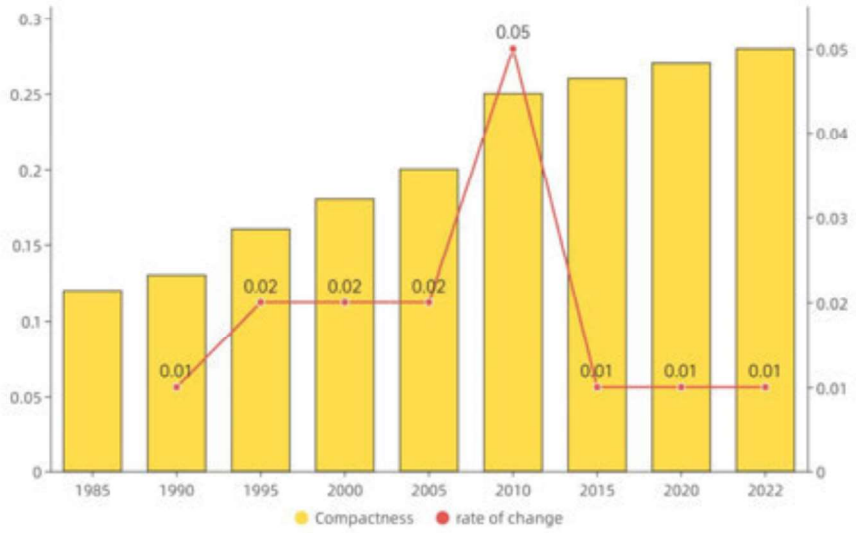

Figure 10 Changes in Shanghai's compactness from 1985 to 2022

The relationship between urban compactness and urban spatial resilience manifests in three critical aspects: ecological environment sustainability, economic vitality enhancement, and social and cultural dimensions resilience.

(1) Sustainability of the Ecological Environment: Compact cities contribute to protecting the natural environment and reducing ecological degradation by minimising land consumption and enhancing land use efficiency (Yao et al., 2022). For instance, by curbing urban sprawl and promoting the construction of high-density residential areas, more natural and semi-natural areas can be preserved, which are crucial for providing ecosystem services such as water retention, air purification, and biodiversity conservation. Furthermore, compact urban forms

help reduce commuting distances and, consequently, lower carbon emissions from transportation, thus mitigating the urban heat island effect and enhancing the overall ecological resilience of the city (Stevenson et al., 2016).

(2) Promotion of Economic Vitality: A concentrated urban layout facilitates the maximisation of resource utilisation and efficiency enhancement (B. Li, 2022). Compact cities can reduce transportation costs and time, enhance business synergies, and accelerate knowledge and technology dissemination. This environment not only attracts more businesses and talent but also fosters innovation and entrepreneurial activities, thereby strengthening the economic resilience of cities. It enables cities to recover and adapt quickly to economic fluctuations or external shocks.

(3) Resilience of Social and Cultural Dimensions: Compact urban environments promote interactions and communications among people from diverse backgrounds, enhancing cultural diversity and social inclusivity (Raman, 2010). This diversity and inclusivity are integral components of social resilience, which can reduce the risk of social fragmentation and conflict during times of change or crisis by strengthening community cohesion and mutual support.

In conclusion, the interconnectedness of urban compactness and spatial resilience spans multiple dimensions, including ecological, economic, and socio-cultural aspects. Urban planners, in their pursuit of urban compactness, should comprehensively consider its impact on the city's overall resilience to ensure more holistic and sustainable urban development.

4.5 Principles and Strategies for Building Shanghai's Urban Spatial Resilience Based on Compactness Elements

Based on the theoretical model of urban spatial resilience and the characteristics of compact urban development, this paper proposes a series of construction principles and enhancement strategies for building urban spatial resilience in Shanghai.

4.5.1 Construction Principles Proposed for Shanghai's Urban Spatial Resilience:

(1) Principle of Mixed Use: Encourage multifunctional land and space use in urban planning and construction, such as integrating commercial, residential, educational, and green spaces to form functionally integrated communities (Verdú-Vázquez et al., 2017). It reduces commuting distances and increases convenience and comfort in daily life (Gaigné et al., 2012). Developers and designers are encouraged to adopt flexible architectural designs, such as variable wall systems and multipurpose rooms, to accommodate future functional changes and diverse usage demands. It enhances the self-sufficiency of communities and provides additional support and buffering in the face of disasters or social upheavals.

(2) Ecological Priority Principle: Prioritise ecological protection and sustainable development in urban planning and expansion. Utilise natural infrastructure such as parks and wetlands to enhance the city's ecological resilience, protect biodiversity, and address urban heat island effects through microclimate regulation and flood risk reduction (Wu et al., 2020). Adopt renewable energy sources like geothermal and solar energy and promote using green building materials to reduce the environmental footprint of urban development and operations (Chel & Kaushik, 2018).

(3) Adaptive Flexibility Principle: Urban design and planning should exhibit high adaptability and flexibility, considering long-term environmental changes, social dynamics, and technological advancements (Jabareen, 2013). For example, the design of buildings and infrastructure should be adaptable to the impacts of climate change(Carter et al., 2015). Develop comprehensive strategies for natural disaster response, including constructing flood barriers, earthquake-safe building standards, and rapid-fire response systems, to effectively enhance the city's resistance and recovery capabilities in the face of natural disasters.

4.5.2 Enhancement Strategies for Building Shanghai's Urban Spatial Resilience:

(1) Strengthen Infrastructure Interconnectivity: Shanghai should continue to improve and strengthen its urban transportation network and public facilities to ensure rapid functional recovery after disasters (S.-C. Liu et al., 2021). Expand multimodal transportation systems, including public transit, bicycle lanes, and pedestrian paths, to reduce reliance on personal vehicles and enhance urban operational efficiency (Y. Li et al., 2024). These measures will enable the city to maintain continuity of operations and services in the face of public health emergencies or other urgent situations.

(2) Promote Green Building and Smart City Technologies: Utilise energy-efficient building materials and intelligent technologies, such as smart grids and automated management systems, to enhance the energy efficiency and operational flexibility of buildings and the city (Um-e-Habiba et al., 2024). Using energy-efficient materials, green roofs, smart grids, and automated systems reduces environmental pollution and increases the city's adaptability to various scenarios (Singh, 2024).

(3) Promote Socio-economic Diversification: Encourage industry diversification and innovation to enhance the city's economic resilience and reduce dependence on single economic sectors. Support the development of small and medium-sized enterprises to improve the economic system's resistance to external shocks. A diversified economic structure can help the city withstand global economic fluctuations and local economic crises(Sheng et al., 2024).

By implementing these principles and strategies, Shanghai can enhance its urban spatial resilience and ensure sustainability and high-quality living for its residents while pursuing compact urban development. These measures strengthen Shanghai's resilience in facing future challenges, including natural disasters, economic fluctuations, and social changes.

5 Conclusion

Constructing resilient cities is one of the critical planning goals for Shanghai's urban development. Based on an interpretation of the definition, connotations, and characteristics of "resilient cities," this paper analyses current issues in Shanghai's urban spatial construction. It explores principles and strategies for enhancing urban spatial resilience in Shanghai, leading to the following six research conclusions.

(1) The Concept, Development, Connotations, and Characteristics of Resilient Cities:

A resilient city is a type of advanced urban form that possesses strong adaptive and learning capacities, effectively responds to significant urban disturbances such as climate change threats, ecological issues, and public health incidents within a particular spatiotemporal scope, promptly restores structural and functional stability, and continues to evolve beneficially. This paper

classifies international research on resilient cities into four stages: nascent, initial, rapid development and reflection of continued development. Analysing the systemic composition, organisational methods, and representational forms of resilient cities reveals that they encompass three essential connotations: urban structure, resilience mechanisms, and resilience representations. These cities also exhibit four categories (encompassing 13 specific characteristics) of essential features: capabilities, structures, mechanisms, and representations.

(2) Definition and Connotations of Urban Spatial Resilience:

Urban spatial resilience is characterised by integrating the three elements of "scale, density, and form" in urban spaces, allowing "urban spatial resilience" to be cognitively expressed as "spatial resilience features." The diversity of urban spatial resilience is evident in the variety of urban functions, choices during impact processes, socio-ecological environments, and multi-scale connections among urban components. The structural organisation of urban spatial resilience exhibits high adaptability and flexibility, manifested in the construction of hierarchical urban spatial structures at macro, meso, and micro levels and in the organisation of social functions.

(3) Theoretical Model of Urban Spatial Resilience:

Based on the connotations and characteristics of resilient cities, this paper has sequentially proposed theoretical models for "resilience" and "urban spatial resilience." The "resilience" theoretical model includes essential elements, operational characteristics, core information, and operational rules. The "urban spatial resilience" theoretical model comprises operational mechanisms, influencing factors, hierarchical structures, organisational rules, intrinsic connotations and representational forms, and system capabilities. The "urban spatial resilience" theoretical model can be applied to analyse the evolution phenomena, construction principles, and enhancement strategies of urban spatial resilience in Shanghai, realising system characteristics of urban spatial resilience that "respond timely to strong disturbances," "maintain and restore the stability of urban structure and functions," and "effectively defend against and address similar issues after experiences or learning."

(4) Evolution, Changes, and Current Issues of Urban Spatial Resilience in Shanghai since 1985:

Since 1985, urban expansion in Shanghai has predominantly displayed a pattern of central concentration with peripheral dispersion, marking a shift from mere rapid expansion to a focus on integrated quality and sustainable development. Urban spatial growth has gradually slowed, and urban compactness has progressively strengthened. Urban development has entered a more mature and stable phase, emphasising ecological protection and sustainable development, thus gradually enhancing urban spatial resilience. The city has moved from concentrated high-speed development in the city centre to more balanced development in the suburbs and new areas. During this process, Shanghai has gradually improved its urban compactness, driving the overall optimisation of transport, public services, and green infrastructure. However, as the city's scale has expanded, Shanghai faces multiple challenges, such as traffic congestion, environmental pollution, social inequality, and disaster response. Future urban planning needs to focus more on finding a new balance between developmental drive and environmental protection, strengthening community participation and technological innovation to build a more resilient and inclusive urban environment, and ensuring sustainable development strategies can effectively address upcoming social and environmental challenges.

(5) Principles and Strategies for Constructing Urban Spatial Resilience in Shanghai:

Based on the theoretical model of urban spatial resilience, the construction of Shanghai's urban spatial resilience should adhere to the principles of multifunctional use, ecological priority and adaptive flexibility. By implementing strategies such as strengthening infrastructure connectivity, promoting green buildings and innovative city technologies, and fostering socio-economic diversification, the city's overall resilience and capacity for sustainable development can be comprehensively enhanced. These strategies significantly improve Shanghai's ability to respond and adapt to natural disasters, economic fluctuations, and social changes, as well as raise the overall standard of urban infrastructure and the quality of life for residents, ensuring a sense of community cohesion and security. Through these integrated measures, Shanghai can achieve a greener, more intelligent, and more humane urban development model, addressing immediate challenges while laying a solid foundation for future sustainable growth, ensuring a harmonious coexistence of urban environments and economic vitality, and thereby achieving comprehensive and enduring urban prosperity and resident well-being.

The current state of urban development across various countries indicates that traditional "safety-defense" disaster prevention concepts no longer meet the needs of contemporary urban risk management. Instead, resilience thinking, which originated in ecology, has come into focus. As an evolving concept, enhancing urban spatial resilience is an effective way to address the risks of urban climate change and follow sustainable development principles and a practical necessity to control chaotic urban sprawl and achieve compact development. The research conclusions of this paper are intended to aid urban managers and researchers in deeply understanding the concepts, connotations, and characteristics of resilient cities and urban spatial resilience. They clarify the principles for constructing urban spatial resilience, the methods for analysing it, and strategies for its enhancement, thereby enabling an appropriate response to the challenges and risks encountered in constructing resilient cities.

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