Transformation and Transition of Urban Spatial Structure in the New Era (Postprint)

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Abstract

Urban spatial structure constitutes a crucial lever for urban sustainable development governance and planning. Scientifically understanding urban spatial structure in the new era is fundamental to deepening urban cognition and achieving harmonious regulation between humanity and nature. This article briefly reviews the historical context of traditional urban spatial structure theories. Through an analysis of technological revolution, policy, and socio-economic environment in the new era, it identifies transformative shifts in the organizational principles, organizational modes, optimization objectives, and component elements of urban spatial structure, thereby elucidating the limitations of traditional theories in explaining urban governance in the new era. It proposes new-era cognitive pathways, including reconstructing the research paradigm of urban spatial structure from the perspective of human-land territorial system theory, re-conceptualizing the carrier space of urban spatial structure, strengthening the analysis of urban spatial structural relationships, and innovating the measurement system of urban spatial structure. The key measures for addressing future challenges in understanding urban spatial structure involve reconstructing urban spatial structure theory, integrating key technologies for urban spatial structure analysis, fusing and applying multi-source data, and constructing a digital twin platform for the optimization and regulation of urban spatial structure.

Full Text

Urban Spatial Structural Change and Transformation in the New Era

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Abstract

Urban spatial structure is a critical lever for urban sustainable development governance and planning. Scientifically understanding urban spatial structure in the new era forms the foundation for deepening urban cognition and achieving harmonious regulation between humans and nature. This article briefly reviews the historical context of traditional urban spatial structure theories and, through analysis of technological revolutions, policy shifts, and socioeconomic environments in the new era, identifies transformative turns in urban spatial structure regarding organizational principles, organizational methods, optimization objectives, and constituent elements. It clarifies the limitations of traditional theories in explaining contemporary urban governance. The paper proposes new pathways for understanding urban spatial structure in the new era, including reconstructing the research paradigm from the perspective of human-land territorial system theory, re-conceptualizing the carrier space of urban spatial structure, strengthening the analysis of urban spatial structural relationships, and innovating the measurement system for urban spatial structure. Key measures for future challenges in urban spatial structure cognition involve reconstructing urban spatial structure theory, integrating key analytical technologies, fusing multi-source data applications, and constructing digital twin platforms for urban spatial structure optimization and regulation.

Keywords: urban governance, urban spatial structure, sustainable development, new era

1. Historical Background of Traditional Urban Spatial Structure Theory

Traditional urban spatial structure theory emerged during the early Industrial Revolution and can generally be divided into material space and social space perspectives. Material spatial structure theory can be traced back to early 20th-century industrial location theory, which analyzed the drivers of industrial site selection from the perspectives of transportation costs and labor expenses. By the 1930s, scholars began focusing on urban spatial form and hierarchical scales, giving rise to classic theories such as central place theory. After World War II, technological progress and innovation meant that transportation costs were no longer the primary locational factor for factories; instead, labor and institutions became important considerations. In the 1960s, issues such as high population concentration and uncontrolled sprawl in large cities drew scholarly attention to urban functional space, represented by theories of linear cities, garden cities, and industrial urban forms. Subsequently, neoclassical, behavioral, and structural schools explained the underlying drivers of urban spatial structure from different angles, including land costs, spatial economic behavior, and capital accumulation. From the 1970s to 1980s, the impacts of network communication technologies and economic globalization on urban spatial structure began to attract attention, leading to the proposal of megapolitan and world city spatial structure theories. Chinese research on urban material spatial structure, drawing upon Western theories, has produced numerous achievements, such as dividing Chinese urban spatial structure into four concentric circles or comprehensively considering the influences of administrative centers, industrial layouts, transportation facilities, and technological innovation on urban spatial structure.

Urban social spatial structure focuses on urban social zoning, represented by the "concentric zone model," "sector model," and "multiple nuclei model." In the 1960s, understanding of urban spatial structure shifted from material space to socioeconomic space. After the 1970s, scholars began emphasizing the formation process of residential space under the influence of residential decision-making, household composition, and housing characteristics. Since the 1990s, globalization and informatization have prompted urban economic, social, and political structures to transition from traditional hierarchical structures to network structures. In the 21st century, research has gradually examined social space from the perspective of residents' daily activities such as living, shopping, and traveling. Meanwhile, "space of flows" theory has gained prominence, with scholars both domestically and internationally understanding urban social structure from the perspectives of information flows, logistics, population flows, capital flows, and technology flows.

Through this review, we find that whether early location theory models or later urban social spatial differentiation models, all have focused on understanding material land use space and the social space built upon it. The "space of flows" perspective has promoted a paradigm shift in social space research. Existing spatial structure analysis research has evolved from spatial economic behavioral mechanisms of "overcoming spatial distance costs" and "pursuing maximum economic benefits" to social processes at technological, economic, social, and political levels.

2. Urban Spatial Structure Transformation in the New Era

2.2 Globalization and Production Networks: Transformation of Urban Spatial Structure Element Organization Under the influence of global value chains and supply chains, spatial connections in industrial and economic activities have continuously strengthened. Economic globalization has promoted rapid development of international trade, with urban capital, commodities, labor, and other elements exhibiting complex changes in scale, direction, and speed of flow. For example, urban internal elements have shifted from flowing from central cities to hinterlands to flowing outward from cities, while multinational corporations forming new industrial spaces in different urban areas have also changed the distribution of agglomeration and dispersion of urban economic elements and the relationships between them. In recent years, China's implementation of regional coordinated development strategies and the "dual circulation" development pattern, along with policy formulation, the evolution of economic development models in the post-pandemic era, and changes in China's role in the globalization process, will continuously reshape and reform the flow patterns and organizational methods of urban spatial structure elements. Under such circumstances, traditional theories explaining the layout of urban economic structural elements appear inadequate when interpreting urban industrial spatial patterns connected by knowledge flows and information flows, requiring us to reconsider urban spatial structure change mechanisms under new economic development situations.

2.3 Shift in Urban Residents' Aspirations: Transformation of Urban Spatial Structure Optimization Goals Residents' aspirations for building livable cities and a better life will propose new objectives for urban spatial structure optimization. In the process of Chinese-style modernization, urban residents' demand for high-quality living is growing increasingly strong, pursuing more comfortable, convenient, healthy, and safe lives with good social atmospheres. Therefore, how to understand urban spatial structure from a "people-centered" perspective, diagnose existing urban spatial problems, and seek localized solutions to guide urban spatial structure elements and spatial flows toward livable city goals is an urgent issue for urban spatial governance under new social development backgrounds. Traditional urban social structure research conducts social zoning based on census data; however, under the guidance of convenience-of-life objectives, future research needs to pay more attention to population activities and derived issues such as spatial accessibility of public services. Previous urban spatial structure research only focused on urban land use space; however, under the goal of a better life, it is necessary to connect people's life satisfaction and health levels with land use space, thereby providing scientific foundations for formulating more livable urban planning and environmental health policies.

2.4 Information and Digital Technology Revolution: Transformation of Urban Spatial Structure Element Composition The current fourth Industrial Revolution, characterized by internet industrialization and industrial intelligence, is and will continue to have a tremendous impact on urban spatial structure. The development of information and communication technologies (ICT) such as 5G networks, 3D printing, the Internet of Things, robotics, and others has promoted urban digital transformation, overlaying virtual cyberspace onto urban material space and reshaping urban spatial structure into a coupled "material space–social space–cyberspace" structure. As an emerging type of urban space, cyberspace includes both physical elements (network infrastructure, hardware devices) and virtual elements (software systems, information flows), which differ significantly from the element composition of material and social spaces. Moreover, cyberspace has systematic impacts on other elements of urban spatial structure. Cyberspace causes the collapse of material spatial structures where spatial accessibility served as a constraining factor, leading to urban "decentralization." According to "socio-technical transition" theory, intelligent services such as remote work, online consumption, social networks, intelligent manufacturing, shared mobility, and urban brains formed through virtual space will make spatial connections of social activities more flexible, elastic, and fluid.

3. Approaches to Understanding Urban Spatial Structure in the New Era

3.1 Reconstructing the Research Paradigm Based on Human-Land Relationship Theory To adapt to urban spatial structure transformation in the new era, greater attention must be paid to changes in system elements, formation mechanisms, and comprehensive effects—goals that traditional theories cannot satisfy. Human-land relationship theory emphasizes characteristics such as wholeness, complexity, and structurality of human-land systems, which aligns well with the features and focus of urban spatial structure in the new era. Therefore, combining human-land territorial system theory to reconstruct the research paradigm allows for re-examination of fundamental questions about urban spatial structure along three key points: First, **complex hierarchy**. Changes in one subsystem or element structure within a human-land system can cause changes in other structures. Understanding urban spatial structure in the new era requires treating cyberspace as a level within the urban human-land system and focusing on complex interactions between cyberspace, material space, and social space. Second, **holistic openness**. Understanding changes in urban human-land system structure under globalization requires fully considering the impact of external socioeconomic environments on the overall urban structure. To identify cross-regional economic, social, and environmental coordination issues, there is an urgent need to reshape the holistic view of urban systems and strengthen research on the remote coupling mechanisms of urban spatial structure spatiotemporal changes. Third, **benefit regulation**. Optimizing human-land systems requires evaluating and selecting spatial organization schemes according to principles of optimal comprehensive benefits. Residents' demand for high-quality living imposes multi-objective requirements on cities, necessitating exploration of the coupling between multiple elements and processes (water, land, air, ecology, people) and investigation of interaction effects between urban material structure, social structure, and network structure to serve the UN 2030 Sustainable Development Goals. In rethinking these fundamental questions about urban spatial structure, complex hierarchy corresponds to different hierarchical compositions of urban spatial structure, holism corresponds to more formation mechanisms, and regulability corresponds to more comprehensive coupling mechanisms. Answering these questions requires innovating research methods and data sources, signifying a systematic transformation of urban spatial structure research paradigms.

3.2 Re-understanding the Carrier Space of Urban Spatial Structure Changes in the carrier space of urban spatial structure in the new era are manifested in, but not limited to, the increasingly strong influence of virtual space on material space under the technological revolution; climate change issues under ecological civilization construction prompting cities to strengthen ecological environmental structure adjustment; social structure changes brought about by immigration issues under harmonious society construction; and the technological revolution driving urban spatial structure analysis systems toward multi-source heterogeneous data applications and intelligent measurement (Figure 1 [Figure 1: see original paper]). We should strengthen systematic organizational structure analysis of cyberspace; understand the impact of urban migrant population influx on urban social-geographical zoning; and focus on spatiotemporal evolution processes of all elements in ecological environmental systems including the biosphere, atmosphere, hydrosphere, and lithosphere. Currently, we have accumulated some innovative understandings of urban carrier space, but these mainly target specific regions or a few elements. Due to data source limitations, we have yet to integrate multi-element, multi-level, and multi-temporal-scale urban spatial structure characteristics to form comprehensive understanding of complex urban human-land system structure.

3.3 Strengthening the Analysis of Urban Spatial Structure Relationships The complex hierarchy, holistic openness, and benefit regulability of system structure all emphasize the "relationship" nature of urban spatial structure, respectively focusing on correlation relationships between important elements, causal relationships between external environments and the overall system, and effect relationships between structures. We should strengthen understanding of interaction mechanisms between virtual space and material/social spaces; comprehend the impact of new socioeconomic issues such as immigration and trade globalization on changes in urban internal social structure; and explore effect relationships between human behavior and environmental-social elements. However, current research on interactions between urban subsystem structures and their elements remains mainly at the conceptual and characteristic description stage, lacking in-depth theoretical and practical exploration of interaction mechanisms, primarily due to the absence of appropriate methods and data sources to visualize and model these multi-dimensional, dynamic, and non-linear interaction relationships. More importantly, existing research has focused on single relationship levels, urgently requiring comprehensive discussion of internal composition relationships within urban subsystems, relationships with external environments, and effect relationships between structures.

3.4 Innovating the Measurement System for Urban Spatial Structure
As urban spatial structure carriers undergo new transformations and cognitive demands for carrier space complexity and interaction relationships increase, there is an urgent need to innovate urban spatial structure measurement systems to meet multi-element, multi-level, multi-scale, uncertainty, and non-linear cognition requirements (Figure 2 [Figure 2: see original paper]). Regarding new data sources, recently emerged "crowdsourced" geospatial big data, due to its fine granularity and rich semantic characteristics, promises to enhance multi-scale, multi-element, and multi-level perception capabilities of urban spatial structure. For example, Points of Interest (POI) data from electronic maps have proven capable of more finely characterizing socioeconomic activity intensity and spatial functional complexity, enabling identification of urban spatial structure at different scales. Individual real-time movement trajectory (LBS) data can reflect urban spatial structure characteristics from the perspective of "observing human behavior." Micro-environmental data from ecological sensor networks and handheld devices further enhance multi-element and multi-scale perception capabilities of urban spatial structure.

Regarding new technical methods, we should fully utilize modern geographic information technology, big data, and artificial intelligence to solve multi-element, complexity, uncertainty, and non-linear cognition challenges in urban spatial structure. Remote sensing and GIS technology combined with ecological theories can support characterization of multi-element transfer processes such as energy flow, material flow, and information flow. Spatial analysis technology can analyze pattern characteristics including topology, direction, distance, density, clustering, and coordination. New spatiotemporal clustering feature mining, spatiotemporal association rule mining, and machine learning methods can simulate potential non-linear relationships between multiple elements. Urban spatial structure display and visualization management systems are currently dispersed across different urban departments and administrative entities. At this stage, we should integrate different data sources and methods through data center platforms to achieve collaborative visualization of urban spatial structure. Therefore, future efforts should employ intelligent exploratory data analysis methods for multi-dimensional expression, coupling relationship simulation, and spatiotemporal visualization management of urban spatial structure. Although some big data-based research has accumulated, most targets urban planning practice, focusing on data and method applications without systematic integration, evaluation, and optimization of data collection, processing, transformation technologies, and modeling analysis methods. Data center platforms also need to evolve beyond previous "collaborative display" functions to achieve real-time perception and regulation of all elements and their relationships in response to urban complex system cognition needs.

4. Key Measures to Address Challenges in Understanding Urban Spatial Structure in the New Era

4.1 Improving Urban Spatial Structure Theory Urban spatial structure theory in the new era should be a multi-perspective integrated theoretical system from carrier space composition to complex coupling relationships within the framework of urban human-land territorial system theory. It needs to focus on theoretical points such as spatial patterns, evolution processes, influencing factors, correlations, and effect mechanisms of urban spatial structure elements, fully summarizing and integrating various element observation, empirical research, and practical application achievements to innovate traditional theories and support urban spatial structure understanding and optimization. In recent years, scholars in related fields have developed numerous urban spatial structure cognition theories, such as space of flows theory, world city networks, and human-land-internet relationship theory, but scientific evaluation of these theories' regional applicability, temporal sustainability, and technical feasibility is still needed to continuously improve the urban spatial structure theory repository.

4.2 Integrating Urban Spatial Structure Analysis Technologies Facing the need for further integration, evaluation, and optimization of current urban spatial structure analysis technologies, we should fully utilize multidisciplinary methods from sociology, environmental science, ecology, and economics to establish a comprehensive model system including geographic information expression models, quantitative evaluation models, scale conversion models, and application analysis models. We should encourage combining spatial relationship quantitative evaluation models with traditional analytical methods such as participatory interviews to establish robust causal chains among various factors. We must fully demonstrate the effectiveness and feasibility of existing mathematical models, spatial analysis, complex networks, visualization, and prediction simulation methods for urban spatial structure analysis. Simultaneously, we need to proactively layout the development of more intelligent methods, preparing technical reserves for advanced methodologies.

4.3 Fusing Multi-Source Data Applications Considering that current new data sources each have their advantages, future efforts should fully integrate and apply these new data sources. Through semantic complementarity between data, we can enhance the expression capability of multi-dimensional and dynamic characteristics of urban spatial structure, and use multi-source data to cross-validate urban spatial structure identification results to reduce uncertainty. We should emphasize not only multi-source new data fusion but also research on combinations of new data and traditional "small data." At the application level, we need to establish urban sky-earth-space data observation, collection, and processing networks, focusing on breakthroughs in efficient association organization and storage technologies for multi-source big data, and technologies for collaborative expression, mining, and knowledge graph construction of multi-element, multi-scale, multi-semantic, and multi-modal features to improve multi-source big data quality and value-added service value. Additionally, establishing sound data sharing mechanisms across multiple regions, departments, and disciplines globally is also important work.

4.4 Building Urban Digital Twin Platforms Addressing the inability of previous data center platforms to accommodate the complexity of urban spatial structure in the new era, future research platforms should start with multi-source data integration and sharing to display all urban elements and processes comprehensively, helping researchers, policymakers, practitioners, and citizens diagnose urban problems and generate knowledge and solutions for understanding or transforming urban space. Digital twin technology is expected to better meet these needs. Future digital twin city construction should enhance the realistic simulation of physical material environments, solving visualization, analysis, and simulation challenges in 3D space, while also enriching visualization expression content in terms of elements, relationships, and events to improve urban structure monitoring and early warning capabilities.

5. Conclusions and Discussion

5.1 Summary Re-understanding urban spatial structure is an inevitable requirement under current trends of globalization, informatization, and sustainable development goals. Urban spatial structure theory established in the early Industrial Revolution and developed to date has shown many inadequacies in current urban research and planning practice, urgently requiring innovation of traditional cognitive systems to meet urban governance needs. Understanding the complex carrier composition and multi-level coupling relationships of urban spatial structure within the context of human-land territorial system theory not only bridges different theories of traditional urban spatial structure spatiotemporal patterns but also establishes a dialogue channel with urban spatial structure analysis schools. We hope the perspectives presented in this paper provide useful references for urban spatial structure research in the new era and offer decision-making theoretical support for national urban governance.

5.2 Future Research Prospects It should be emphasized that the new theoretical perspectives proposed in this paper require empirical testing and continuous improvement and deepening in subsequent research, with trade-offs needed for different research scales and urban development stages. For example, at the global scale, we should adopt a holistic perspective to study overall urban changes under new economic environments; at the city scale, we should approach from complexity and regulability perspectives, focusing on issues of urban economic-social-environmental relationships. In Europe and America, most cities have entered the late stage of urbanization and are moving toward regionalization and globalization—characteristics suitable for holistic interpretation. For cities in rapid industrialization, urbanization, and socioeconomic transition stages, comprehensive examination should proceed from complexity and regulability thinking.

Currently, China faces a series of urban problems and challenges in its rapid urbanization and socioeconomic transformation process. Urban population is growing far faster than in Western developed countries; large cities have high population density; unlike Western cities influenced by racial and family factors, Chinese urban social structure involves the proportion of migrant population, occupational types, housing conditions, and education levels. Urban spatial governance faces challenges such as population agglomeration, excessive commuting, unfair distribution of medical and educational resources, "urban villages," and "urban fringe areas." Solving these problems requires theoretical support with Chinese characteristics. In future urban spatial structure cognition and planning regulation, special attention should be paid to regions with tense human-land relationships, strengthening cognition of typical urban spatial structures such as traditional old industrial areas, ecologically fragile zones, deeply impoverished areas, and urban continuous zones. Answering major scientific questions with both theoretical and practical significance—such as "How to identify boundaries of production, living, and ecological spaces from a human behavior perspective," "How does cyberspace affect urban land use intensity," and "What are the spatial transmission mechanisms of industrial restructuring, ecological reconstruction, and social transformation"—will help strengthen understanding and optimization of urban spatial structure in the new era, establish typical paradigms for promoting coordinated and sustainable urban system development, and provide important value and practical significance for supporting China's major strategies of urban-rural integration, Beautiful China, and ecological civilization construction. Meanwhile, research on typical Chinese urban spatial structures can also promote knowledge production based on Chinese experience and contribute to international theoretical comparative studies.

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