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Spatial Development Intensity Research: Progress in China and Global Perspectives

Bohang Zhang, Jianguo Wang*

Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia
Email: Bohang.Zhang@student.uts.edu.au, *jianguo.wang@uts.edu.au

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Abstract

Spatial development intensity (SDI) is widely used to evaluate land development and human activity intensity in territorial space. With rapid global urbanization and industrialization, its measurement, regulation and sustainability have attracted extensive attention. Nevertheless, inconsistent concepts, indicator systems and measurement methods have led to fragmented research. This paper reviews the conceptual evolution, indicator systems and measurement methods of SDI, and compares domestic and international research paradigms. Early studies mainly adopted single indicators, while recent studies tend to use multidimensional comprehensive systems combined with remote sensing, GIS and spatial econometric models. Challenges still exist in spatial heterogeneity, resource-environment carrying capacity and planning application. Future research should strengthen multi-source data integration, spatial modeling and planning practice to support refined regulation and sustainable development.

Keywords

Spatial Development Intensity, Evaluation Indicators, Sustainable Development

1. Introduction

Space serves as the material carrier of human activities, and its rational development and construction constitute an important foundation for promoting resource conservation and intensive utilization as well as for effectively protecting the ecological environment. SDI directly reflects the degree of intensive use of construction land and the frequency of human activities within a region, and provides a comprehensive representation of the level of urban spatial development and its cumulative carrying density (Desmet & Rossi-Hansberg, 2010). Accord-

ingly, SDI can be regarded as an integrated indicator of development and construction activities within terrestrial space, and has gradually become an important tool for governments to implement overall spatial development control and to scientifically optimize spatial structure (Unwin, 1996).

With sustained global economic growth and the continuous advancement of industrialization and urbanization, SDI has generally exhibited an upward trend, accompanied by significant transformations in spatial development patterns (Gong et al., 2014). However, against the backdrop of increasingly stringent resource constraints and growing ecological and environmental pressures, mismatches between SDI and resource-environment carrying capacity have become increasingly pronounced. Overexploitation of land resources and excessive reliance on resource-intensive growth models have resulted in disorderly expansion of construction land and rapid loss of cultivated land, further exacerbating regional spatial imbalance, widening urban-rural disparities, intensifying environmental pollution, and accelerating ecological degradation (Gu et al., 2023).

Under these circumstances, guiding and regulating urban spatial development in a rational manner has become a critical component of regional sustainable development and a key task in promoting high-quality socioeconomic growth. Therefore, a review of existing research and practice on SDI—clarifying its conceptual foundations, synthesizing China and international research progress, and identifying future research directions—is of significant value for the scientific regulation of SDI and for advancing sustainable urban and regional development.

2. The Concept and Historical Development of SDI

2.1. Basic Conception

The concept of space originated in Western philosophical and geographical thought, and its connotations have continuously expanded with the evolution of research paradigms. From a spatial perspective, space can be understood as a three-dimensional geographical entity composed of land, water bodies, and their overlying elements, serving as the fundamental carrier for the interaction between natural processes and human activities (Serge Viderman, 1979). When its social attributes and functional characteristics are further considered, space is no longer regarded as a purely physical container, but rather as a multi-element composite system formed through the interaction of natural resources, ecological environments, and socioeconomic activities, exhibiting features of openness, dynamism, and hierarchical structure (Mazúr & Urbánek, 1983).

Within this evolving conceptual framework, a number of related intensity-based concepts have emerged from different research traditions, among which land-use intensity and construction land development intensity (CLDI) represent two important analytical branches in the development of SDI research. Land-use intensity generally refers to the degree of input and output in land utilization processes, often emphasizing the relationships between resource inputs, management practices, and production or economic outputs, and is widely applied in agricul-

tural and resource-based studies (Semenchuk et al., 2022). In contrast, CLDI focuses on the scale, density, and efficiency of construction land development, typically measured through indicators such as construction land proportion, development density, and land output intensity, and is more closely associated with urbanization processes and spatial expansion (Chen, Xu, Cao, Zhu, & He, 2025a). Although these concepts differ in their analytical focus and measurement approaches, they both capture partial dimensions of humamn-land interactions and have provided important methodological foundations for the evolution of SDI. Building upon these research streams, SDI has gradually developed into a more comprehensive and integrative framework that not only incorporates the scale and efficiency of land development, but also emphasizes spatial structure, functional coordination, and planning regulation, thereby enabling a more systematic understanding of the interactions between human activities and spatial resources.

In practice, SDI is commonly used to characterize the degree to which human construction activities occupy space, and is often measured by the proportion of construction land area to the total area of a given region. As a key concept in spatial planning and development management, SDI not only reflects the scale characteristics of construction activities, but also reveals, to some extent, patterns of spatial resource allocation and their potential environmental and social impacts (Tang & Yiu, 2010). With the deepening of research, some scholars have further adopted a systems perspective, arguing that SDI should not be viewed as a simple outcome of land use change, but rather as a composite measurement index arising from the interactions among resources, environment, population, and socioeconomic factors within a spatial system. Accordingly, the construction of multidimensional evaluation indicator systems for SDI has been advocated. Overall (**Figure 1**), the conceptual understanding of SDI has gradually evolved from an early focus on single land-based indicators, such as construction land scale, toward a comprehensive evaluation system that reflects the interactive relationships and supply-demand matching between human activities and spatial resources (Brown & Vivas, 2005).

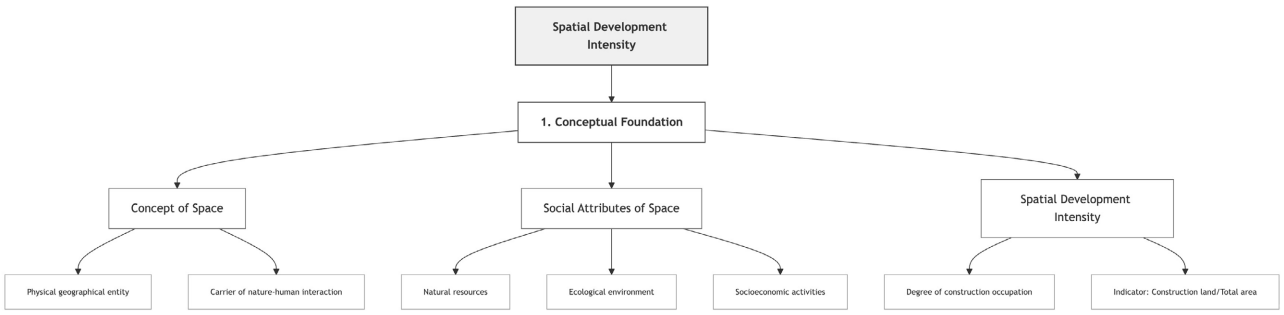

Figure 1. Conceptual foundation of SDI.

Although differences remain between China and international scholars regarding the conceptual definition and measurement priorities of SDI, theoretical ex-

ploration and practical research centered on urban development processes and construction land regulation have been continuously advanced, forming a relatively solid research foundation in the fields of spatial planning and urban management. From a research perspective, international studies have largely examined SDI through the lenses of land use change and human-land relationships, with research themes encompassing land use development and management, spatial regulation and smart growth strategies, as well as the relationships between land development, socioeconomic processes, and ecological and environmental impacts.

2.2. Conceptual Evolution of SDI in International Research

The conceptual origins of SDI can be traced back to the early development of modern urban planning theory. As a pioneer of modern urban planning, Howard proposed the Garden City concept, which sought to define an appropriate urban scale through land-use zoning and the delineation of urban boundaries, thereby laying an early conceptual foundation for controlling the intensity of spatial development (Richert & Lapping, 1998). Subsequently, (Schein, 1993) further advanced national land and spatial planning research by emphasizing that spatial planning should incorporate block-level spatial surveys and systematic analyses from the very beginning of the planning process, marking a shift from experience-based guidance toward a more systematic understanding of spatial development.

At the beginning of the twentieth century, developed countries began to explore national and spatial planning practices at the institutional level. In Europe, the United Kingdom, as a forerunner in urban and spatial planning, established a relatively comprehensive planning system through legislative instruments such as the Housing and Town Planning Acts and the Town and Country Planning Act. The establishment of this legal framework signified the gradual maturation of the UK's spatial planning system and its capacity to address issues arising from spatial development and management through diverse planning theories and policy tools (Reimer, Getimis, & Blotevogel, 2014). In France, early spatial planning practices were more closely aligned with national land improvement initiatives. Through regional urban planning, administrative areas were zoned in accordance with the Urban Planning Law and the National Land Improvement, Beautification and Expansion Plan, thereby promoting the orderly governance of spatial development (Albrechts, Balducci, & Hillier, 2016). The Netherlands was among the earliest countries to establish a national-level spatial planning authority; supported by effective coordination across governmental levels, spatial planning policies were successfully embedded into development management processes at multiple scales (Haughton & Allmendinger, 2018).

The promulgation of Agenda 21 further raised global awareness of the need to coordinate resource use, ecological protection, and economic development. Since then, the principles of sustainable development have been increasingly integrated into spatial planning practices worldwide, providing new directions for the ad-

vancement of spatial planning and spatial development management. Building upon this foundation, scholars and policymakers have continued to refine spatial planning and development practices in accordance with national contexts and development stages, gradually shifting the focus from simple scale control toward a more comprehensive consideration of efficiency, spatial structure, and ecological constraints. This evolution has provided an important theoretical and institutional backdrop for the emergence and development of the concept of SDI (Figure 2).

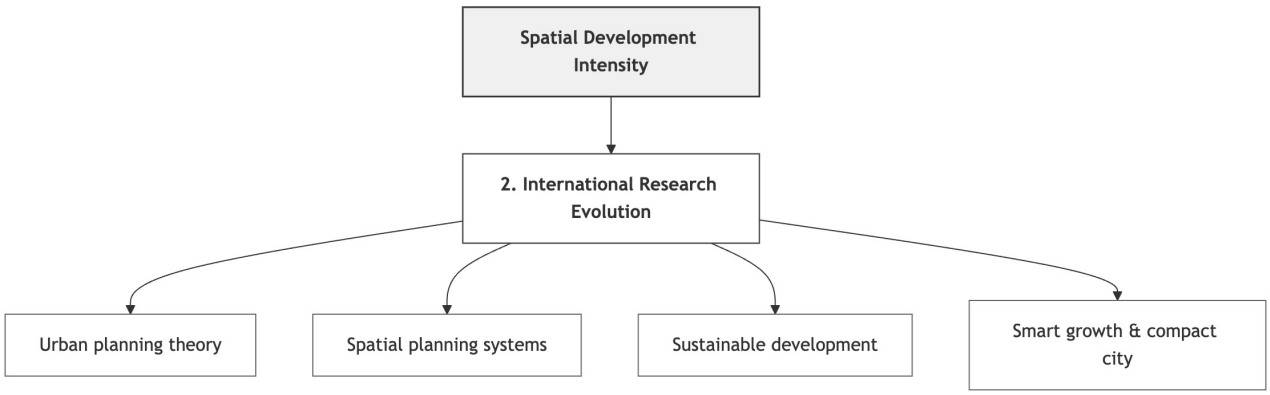

Figure 2. International research evolution.

2.3. Current Status of International Research on SDI

With the progressive deepening of sustainable development concepts, numerous international studies have integrated spatial planning with development practices and conducted more comprehensive and detailed analyses in accordance with national contexts and development stages (Local Agenda 21: Planning for the future, changing today, 2019). From the perspective of ecological and landscape environmental impacts, (Ghosh, Vale, & Vale, 2007) examined the relationship between land development and water resource balance in New Zealand, arguing that governments should enhance public governance capacity to improve sustainable resource management. Subsequently, (Na, Shi, & Guo, 2023) employed a geographically weighted regression (GWR) model to explore the spatiotemporal patterns and driving mechanisms of ecosystem health in relation to climatic, socioeconomic, and natural resource factors, further extending research on the coupling between spatial development and ecological processes.

In the field of urban land development, (Correia & Roseland, 2022) highlighted the negative externalities associated with urban expansion and reviewed development outcomes under growth management approaches based on existing peer-reviewed literature. Their findings suggest that growth management strategies can effectively control urban land expansion and excessive increases in population density. Meanwhile, (Ferdous & Bhat, 2012) introduced the concept and indicators of urban land use development intensity to evaluate the level of land development in urban areas, defining it as a measure of the relative degree of land de-

velopment and its cumulative carrying density. Since then, the concept of SDI, emphasizing regulated land use intensity and development, has been incorporated into spatial development research, leading to a growing body of related studies.

Regarding conceptual definitions, (Dietrich et al., 2012) defined land-use intensity as the level of socioeconomic inputs and human activities per unit area and time, arguing that land-use intensity indicators are more effective than simple land-use area measures in capturing human capacity to utilize land resources. In this sense, SDI has been demonstrated to provide a more comprehensive description of the capacity and degree of spatial development. As urban sprawl has become a common challenge in Western countries, planning concepts such as urban growth boundaries (Gennaio, Hersperger, & Bürgi, 2009) and the compact city (Van der Waals, 2000) have increasingly influenced urban management and spatial development decision-making.

2.4. Conceptual Evolution of SDI in China

China studies on SDI have primarily focused on construction land-related issues, including the expansion of construction land and its driving mechanisms (Ye et al., 2013), construction land development efficiency (Wang, 2018), the relationship between construction land development and the ecological environment (An, Xiao & Huang, 2023), and the optimization of construction land structure (Li, Wang & Liu, 2021). In addition, some studies have examined the effectiveness of construction land planning and regulatory controls (Zhou et al., 2017). From a spatial perspective, existing research has been largely concentrated in economically developed regions or areas subject to stringent resource and environmental constraints, while relatively limited attention has been paid to less developed or ecologically sensitive regions.

In China's academic research and planning practice, studies on spatial development have not remained at the level of general spatial analysis, but have gradually been incorporated into a governance-oriented institutional framework, giving rise to a research and practice system centered on territorial spatial planning. Compared with traditional spatial planning, territorial spatial planning places greater emphasis on the overall coordination and control of development activities within the spatial structure, and guides development scale and spatial layout through institutionalized regulatory instruments (Liu & Zhou, 2021). Within this context, research on urban development and construction land regulation has continued to deepen, forming a research orientation in which territorial spatial development constitutes a central analytical object. Accordingly, it is necessary to review China research progress in this field to provide theoretical and methodological support for subsequent analysis.

In terms of research focus and policy orientation, studies on territorial SDI have, on the one hand, closely followed policy documents issued by the Ministry of Land and Resources (now the Ministry of Natural Resources), aiming to clarify the connotations of development intensity and to strictly maintain the balance

between permanent basic farmland protection and land resource utilization. On the other hand, research has increasingly emphasized the optimization of spatial development patterns, highlighting improvements in development quality and regulatory order, and integrating development intensity into scientific approaches to comprehensive urban spatial regeneration and management (Ge & Lu, 2021). In recent years, with the continuous advancement of the ecological civilization strategy, territorial SDI has become a key supporting element of the overall territorial spatial planning framework. At the same time, resource-environment carrying capacity, driven by the integrated promotion of land resource development, protection, and remediation, has emerged as a closely related research frontier (Yue et al., 2023).

From the perspective of policy evolution, China has progressively strengthened the regulation of territorial SDI. Beginning with the issuance of the National Main Functional Area Planning, efforts were made to promote a territorially coordinated development pattern balancing population, economy, resources, and the environment. Subsequently, the 13th Five-Year Plan introduced a dual-control policy on the total amount and intensity of construction land, together with measures to optimize the spatial structure of territorial development and protection (Wang & Shen, 2014). More recently, the Guidelines for the Compilation of Provincial Territorial Spatial Plans (2020) explicitly identified development intensity as an anticipatory indicator for construction activities, calling for strict control over newly added construction space and continuous improvements in land-use efficiency. This policy trajectory reflects an ongoing shift from nationwide regulation toward increasingly refined, scientific, and stringent development intensity controls at the provincial and sub-provincial levels (Chen et al., 2020).

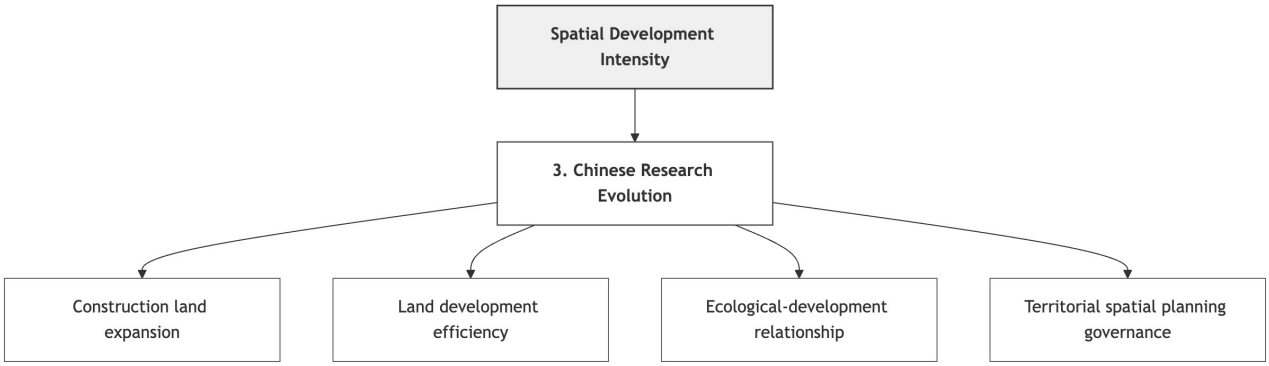

Figure 3. Chinese research evolution.

Concurrently, the connotation of territorial SDI has continued to expand, evolving from a focus on localized construction management toward comprehensive governance of territorial space as a whole (**Figure 3**). The analytical scope has also extended from construction land alone to the coordinated development of construction and non-construction land. As a result, territorial SDI has become a

key indicator in regulatory detailed planning, and its rational control has emerged as an essential component in improving China's territorial spatial planning system.

2.5. Current Status of China Research on SDI

Overall, the rise of China research on SDI is closely associated with the advancement of China's territorial spatial planning system. Against the backdrop of intensified territorial spatial plan compilation, territorial SDI has gradually become an important research focus within the discipline of land resource management. Since the founding of the People's Republic of China, China's territorial spatial development practices have generally followed economic development patterns, with relevant initiatives promoted at both macro and micro regional scales. Except for the period of the Third Front Construction, a spatial development pattern characterized by a "point-axis system" gradually took shape nationwide (Hu et al., 2023). In this process, the concept of development intensity emerged alongside national economic development and was progressively introduced into academic research and policy discourse.

Since the reform and opening-up period, the acceleration of industrialization and urbanization has driven sustained economic growth and expanding spatial development. However, this process has also given rise to prominent problems, including imbalances in territorial spatial structure, extensive and disorderly development, encroachment on ecological space, and excessively high urban SDI (Zhou et al., 2014). In response, early studies under conditions of high development intensity increasingly emphasized comprehensive development approaches that adhere to ecological principles and integrate the multifunctional attributes of natural resources, aiming to alleviate development pressure by improving resource use efficiency. As urbanization further accelerated, research attention shifted toward urban land development issues, explicitly introducing the concept of urban land development intensity and highlighting the necessity of scientifically forecasting and evaluating land development intensity to prevent environmental quality degradation caused by overdevelopment.

Entering the 21st century, national strategies such as the revitalization of old industrial bases in Northeast China, the Western Development Strategy, and the rise of Central China elevated regional development to the level of overarching national policy. Consequently, China's territorial spatial development pattern exhibited a clear trend of expansion from eastern regions toward central and western regions, with SDI increasingly shaped by regional economic dynamics (Yang et al., 2021). During this period, academic research on territorial spatial development and development intensity became more refined and in-depth. (Yue et al., 2012) conducted zoning-based analyses of development intensity in Shanghai's central urban area at macro, meso, and micro scales, proposing that land development should be guided to better balance equity and efficiency. Furthermore, the report of the 17th National Congress of the Communist Party of China explic-

itly identified the delineation of main functional zones as a key objective of national territorial development, and the Outline of the Eleventh Five-Year Plan formally established this objective as a major strategic task for advancing territorial spatial governance. In line with this goal, (Wu et al., 2021) argued that agglomerated development combined with functional zoning constitutes a strategic choice for territorial spatial development, and proposed a multi-center network-based agglomeration pattern to enable effective regulation of development across the entire territorial space.

In the new development stage, with the implementation of the Belt and Road Initiative and the issuance of policy documents such as the National Land Resources 13th Five-Year Plan and the National Territorial Spatial Plan Outline (2016-2030), increasing emphasis has been placed at the national level on regulating SDI from the perspectives of orderly territorial development and human-land system sustainability. Accordingly, territorial SDI has gradually become a core issue in studies addressing resource–environment constraints and spatial pattern optimization. (Fan et al., 2019) suggested that the Guangdong-Hong Kong-Macao Greater Bay Area should pursue a development pathway oriented toward compact and green cities, emphasizing smart growth, strengthening urban ecological infrastructure, and constraining high-density and high-intensity urban development to sustain ecological functions—an approach consistent with future urban development trajectories.

Under the goals of ecological civilization and "Beautiful China," and in line with the requirements of implementing the territorial spatial planning system, there is an urgent need to more scientifically measure territorial SDI, clarify the rigid constraints imposed by resource-environment and natural conditions on construction land expansion, and, on this basis, rationally delineate urban development boundaries, so as to guide the optimization of future territorial spatial development patterns and structures.

2.6. Progress in Evaluation Indicator Systems and Measurement Methods of SDI

A review of international studies conducted between approximately 2000 and 2024 suggests that the evaluation of SDI has progressively evolved from simplified single-indicator measurements toward more comprehensive composite indicator systems. In earlier research, spatial development levels were commonly represented by relatively straightforward indicators, including land-use intensity, the proportion of built-up land, or floor-area ratios. While these measures provided convenient quantitative descriptions of development levels, they were limited in capturing the multidimensional interactions between human activities and spatial resources. With the increasing complexity of urban systems and the growing emphasis on sustainable development, more recent studies have increasingly adopted multidimensional evaluation frameworks. These frameworks typically integrate indicators related to population density, economic productivity, land-use effi-

ciency, and ecological or environmental constraints, allowing for a more systematic assessment of spatial development processes. Evidence from international literature indicates a clear methodological shift: early evaluations primarily relied on single-indicator measurements, whereas contemporary research increasingly adopts composite indicator systems. This shift highlights the growing preference for integrated evaluation approaches that better reflect the complex relationships among socioeconomic development, land resource utilization, and environmental sustainability.

2.7. Evolution of Evaluation Indicator Systems and Measurement Methods for SDI in China

With the progressive advancement of research on SDI, its conceptual connotations and evaluation frameworks have exhibited distinct characteristics across different development stages. Accordingly, the construction of evaluation indicators and the selection of measurement methods have become increasingly diversified. Based on reviews of the China and international literature, existing evaluation indicators for SDI can generally be classified into two categories: single indicators and composite indicator systems (Qiu et al., 2025). The evolution of these two types of indicator systems roughly corresponds to the implementation process of the main functional zone planning. Specifically, the period prior to the promulgation of the National Main Functional Area Planning can be regarded as an exploratory stage of composite indicator systems; the period between the release of the main functional zone planning and the trial implementation of the territorial spatial planning system represents a stage in which single indicators were more proposed; and the subsequent period marked by the full implementation of the territorial spatial planning system under the "multi-plan integration" framework corresponds to a stage of in-depth exploration of composite indicator systems.

During the initial exploration of composite indicator systems, some studies examined spatial development intensity (SDI) through the perspective of construction land development intensity (CLDI), using panel data from 31 provincial-level administrative units in China. An evaluation framework was developed based on construction land occupation, population carrying capacity, and economic output, with indicators such as construction land density and land output intensity. Methods including the Theil index, spatial autocorrelation analysis, and geographic detector models were used to analyze spatiotemporal patterns and regional differences. While CLDI provides a useful proxy for SDI by capturing the intensity of construction land use, it mainly reflects development scale and output, and does not fully incorporate dimensions such as spatial structure and planning regulation emphasized in SDI.

With the expansion of research perspectives, Chinese studies have increasingly incorporated efficiency considerations into SDI evaluation by developing integrated frameworks that combine development intensity and land-use efficiency. Taking the Yangtze River Delta urban agglomeration as a case, relevant research

constructed a coupling evaluation framework linking built-up land development intensity (BUI) and land-use efficiency (LUE) to address the tension between rapid spatial expansion and sustainable development. In this framework, BUI was measured using indicators of horizontal spatial extent and vertical development intensity, while LUE was quantified through multi-source data such as nighttime light, land surface temperature, population density, GDP, and points of interest. A coupling index was further applied to assess the coordination between development intensity and efficiency, and to classify built-up land into different types, thereby providing methodological support for differentiated spatial regulation (Ruan et al., 2022).

Overall, research in China has progressively expanded the understanding and evaluation of spatial development intensity (SDI) by incorporating multiple analytical perspectives, including land-use intensity, construction land development, and efficiency-oriented approaches. These studies have not only enriched indicator systems and methodological frameworks, but also advanced the interpretation of SDI from single-dimensional measures toward integrated analyses that consider scale, structure, and efficiency. In this context, the interaction between SDI and resource-environment constraints has emerged as a key focus of sustained academic attention, highlighting the need to balance development intensity with ecological and spatial carrying capacities.

2.8. Evolution of SDI Evaluation Indicators and Measurement Methods in International Research

Overall, international studies place greater emphasis on the ecological constraint attributes of evaluation indicator systems and the spatially explicit expression of measurement methods, providing important theoretical and technical references for the scientific measurement and planning regulation of SDI. Compared with China research, international studies in this field started earlier, and related achievements have mainly originated from research on land use/land cover change (LUCC), urban sprawl, and sustainable development (Viana et al., 2019).

In terms of evaluation indicator systems, early studies primarily approached SDI from the perspectives of land-use structure and construction land expansion. Indicators such as the proportion of built-up areas, impervious surface ratio, population density, and employment density were commonly used to quantitatively characterize SDI, with a focus on the scale and agglomeration characteristics of spatial development. With the advancement of ecological economics and human-land system science, subsequent research gradually incorporated factors such as resource consumption, ecological impacts, and environmental carrying capacity into evaluation frameworks. This led to the formation of multidimensional indicator systems encompassing land development intensity, energy consumption intensity, ecological footprint, and environmental pressure, aiming to comprehensively reflect the impacts of development activities on natural systems.

Regarding measurement methods, international studies have extensively ap-

plied remote sensing and GIS techniques. Multi-temporal remote sensing imagery has been widely used to identify changes in construction land and impervious surfaces, while spatial statistical analysis, landscape pattern indices, and urban morphology indicators have been combined to measure the spatial heterogeneity of SDI. In addition, some studies have introduced ecological footprint models, carrying capacity models, and scenario simulation approaches to explore threshold levels and sustainability boundaries of SDI under different development pathways.

In the field of agricultural and SDI research, (Dietrich et al., 2012) conceptualized intensity from the perspective of production activity intensity, emphasizing the role of human inputs such as research and development, infrastructure, and management. They introduced an alternative indicator based on the relationship between actual yield and reference yield under standardized technological and management conditions, allowing the exclusion of natural constraints such as soil quality and climate variability. Using reference yields simulated by a global crop growth model, the study conducted a comparative analysis across multiple world regions and crop types. However, this production-oriented perspective differs from SDI as applied in urban and regional planning, where the focus lies on the intensity of spatial development and land-use configuration, typically reflected through indicators such as development density, land-use structure, and planning control mechanisms, rather than purely on input-output relationships in agricultural production.

Furthermore, (Insa Kühling, Broll, & Trautz, 2016) examined intensity in the Western Siberian grain belt under a transitional economic context and developed an input-oriented measurement framework based on agricultural production factors. Using subnational annual statistical data, separate intensity indices were constructed for cropland and grassland, and spatiotemporal variations were analyzed at both provincial and district scales. Principal component analysis (PCA) was employed to integrate intensity measures across different land-use types and to explore their relationships with biophysical conditions. The results revealed significant differences in intensity dynamics among land-use types as well as clear spatial clustering patterns, demonstrating the regional applicability of the proposed approach. However, similar to other production-oriented intensity studies, this framework differs from SDI in that it primarily captures variations in input levels and production processes, whereas SDI emphasizes the intensity of spatial development, land-use structure, and planning regulation within urban and regional systems.

At the theoretical level, (Erb et al., 2013) proposed a comprehensive conceptual framework for measuring and monitoring intensity, emphasizing that intensity should be examined across multiple dimensions, including inputs, outputs, and unintended system-level impacts arising from human activities. This multidimensional perspective provides an important theoretical reference for understanding SDI, particularly in highlighting the need to integrate process-oriented and out-

come-oriented dimensions in intensity evaluation, although its original focus is rooted in production and land-system analysis rather than spatial development regulation. In summary, the construction of evaluation indicator systems and the selection of measurement methods remain core issues in SDI research within urban and regional planning. Across different spatial scales, development objectives, and regional contexts, existing studies have progressively refined indicator design and methodological approaches, demonstrating a transition from single-indicator assessments to multidimensional comprehensive frameworks, and from experience-based judgment to quantitative and model-based analysis (Estoque & Murayama, 2015). However, several challenges persist in practical applications. On the one hand, different measurement approaches exhibit varying sensitivity to spatial heterogeneity and scale effects, resulting in limited comparability and stability in cross-regional or cross-scale evaluations. On the other hand, some indicator systems tend to emphasize development outcomes while insufficiently incorporating process-related factors such as resource-environment constraints, functional coordination, and spatial carrying capacity, thereby constraining their applicability in planning practice. Consequently, improving both the accuracy of measurement and the planning relevance and explanatory capacity of indicator systems remains a key direction for advancing SDI research.

3. Comparative Review of Evaluation Indicator Systems and Measurement Methods for SDI

A comparison between research in China and international studies reveals notable differences across four key dimensions: conceptual understanding, indicator systems, methodological approaches, and planning applications.

From a conceptual perspective, international research generally situates SDI within the broader frameworks of land use, urban planning, and sustainable development, emphasizing the interactions between human activities and natural systems as well as ecological constraints. In contrast, research in China is primarily grounded in the territorial spatial planning framework, where SDI is regarded as an important tool for regulating the balance between development and protection, reflecting a strong planning orientation and policy relevance (Mi et al., 2023).

In terms of indicator systems, international studies tend to adopt multidimensional evaluation frameworks that integrate land-use intensity, resource consumption, ecological footprint, and environmental carrying capacity to capture the comprehensive impacts of development activities. By comparison, research in China is more closely aligned with planning practices, with indicator systems typically centered on construction land scale, population carrying capacity, and economic output, while gradually incorporating dimensions such as efficiency, structural optimization, and resource-environment constraints, reflecting a transition from single indicators to integrated evaluation systems.

Regarding methodological approaches, international research widely employs remote sensing, GIS-based spatial analysis, landscape metrics, and spatial model-

ing techniques to capture spatial heterogeneity and dynamic processes, and in some cases introduces scenario simulation and ecological models to explore sustainability thresholds (Chen et al., 2025b). Meanwhile, research in China also demonstrates strong capacity in methodological integration, with extensive applications of remote sensing data, multi-source spatial data fusion, and spatial econometric methods. A research paradigm has thus been formed that is based on index construction, spatial statistical analysis, and econometric modeling, while increasingly extending toward spatially explicit analysis and multi-source data integration.

From the perspective of planning application, international studies tend to focus on supporting sustainable urban development and spatial governance, emphasizing ecological protection, resource constraints, and long-term development pathways. In contrast, research in China is more deeply embedded in territorial spatial planning practices, serving as a key tool for regulating construction land expansion, optimizing spatial structure, and supporting multi-level planning implementation.

Overall, international research shows advantages in ecological integration and theoretical framework development, whereas research in China demonstrates stronger relevance to planning practice and policy implementation. Future research should seek to integrate these strengths by enhancing the representation of ecological constraints while improving methodological integration and planning applicability, thereby advancing spatial development intensity research toward more systematic and refined approaches.

4. Summary

Overall, quantitative measurement of SDI remains insufficiently developed, particularly with respect to clarifying the relationship between resource-environment constraints and territorial spatial development and protection, which has increasingly become a key scientific issue in the fields of territorial spatial planning and resource-environment management. Based on a synthesis of existing studies, current research on spatial development intensity can be broadly summarized from three perspectives: research perspectives, research methods, and research scales.

4.1. Research Perspectives

In terms of research perspectives, some studies adopt the viewpoints of resource and environmental carrying capacity and land-use change, focusing on the status of resource-environment carrying capacity, the dynamic evolution of land-use patterns, and the spatiotemporal expansion of construction land, while further exploring their driving mechanisms. Meanwhile, other studies approach the issue from the perspectives of land development degree and utilization efficiency, emphasizing the impacts of land development activities on the natural environment, ecosystem services, and biodiversity, and revealing the interactive relationships between SDI and the ecological environment.

4.2. Research Methods

With regard to research methods, a wide range of techniques has been employed, including cellular automata (CA) models, grey relational analysis, multiple linear regression, logistic regression, path analysis, and geographic detector models, to identify and analyze the variation characteristics of SDI and the dominant factors driving construction land expansion (Kucsicsa & Grigorescu, 2018). These methods have played an important role in uncovering development patterns and underlying driving mechanisms.

4.3. Research Scales

In addition, the combined application of remote sensing interpretation and GIS-based spatial analysis has gradually become mainstream, effectively improving the spatial accuracy and reliability of SDI measurements. In terms of research scale and spatial coverage, existing studies are mainly conducted at the municipal level and above, with a growing number of studies focusing on urban agglomerations and river basin units. Spatially, research areas are predominantly concentrated in economically developed eastern regions, while relatively limited attention has been paid to central and western regions. Overall, current studies on the spatial characteristics of development intensity remain largely descriptive, with insufficient empirical analysis of spatial autocorrelation. Moreover, influencing factor selection tends to emphasize population, economic, and social variables, while natural geographical constraints and planning policy factors are relatively underrepresented. Methodologically, traditional econometric models are still dominant, and limited attention has been given to the spatial dependence of land-use data and the non-stationarity of geographical processes.

5. Prospects and Future Directions

A review of existing studies indicates that substantial progress has been made in understanding the theoretical connotations, evaluation indicator systems, and measurement methods of spatial development intensity. However, further advances are still required to better support refined spatial regulation and high-quality development goals within the territorial spatial planning framework. Future research may be advanced in the following key directions.

First, greater emphasis should be placed on the systematic integration of rigid resource-environment constraints. Building upon indicator systems that currently focus on construction land scale, population, and economic factors, future studies should place stronger emphasis on process-oriented expressions of ecosystem services, environmental capacity, and natural geographical conditions, thereby promoting a transition from outcome-oriented assessment toward analyses based on "carrying capacity-response-feedback" mechanisms.

Second, efforts should be made to enhance the adaptability of measurement methods to spatial heterogeneity and scale effects. On the basis of traditional econ-

ometric models, further integration of spatial econometric approaches, geographically weighted models, multiscale analysis, and scenario simulation techniques is needed to improve the stability and explanatory power of cross-regional and cross-scale comparisons.

Third, future studies should strengthen the integrated application of multi-source data and spatially explicit measurement approaches. By fully leveraging emerging data sources such as remote sensing imagery, nighttime light data, POI data, and other forms of big data, SDI measurement can be advanced from evaluations based on statistical units toward continuous spatial representation, providing more intuitive technical support for refined spatial planning and regulation.

Fourth, greater attention should be given to strengthening the coupling between SDI assessment and planning instruments. Enhanced application of development intensity measurement results in the delineation of urban development boundaries, zoning for land-use regulation, and differentiated regulatory strategies will improve the operational feasibility and decision-making value of evaluation indicator systems in territorial spatial planning practice.

Overall, future research on SDI should strive to establish stronger linkages among theoretical integration, methodological innovation, and planning application, thereby providing more robust support for the modernization of territorial spatial governance systems and governance capacity.

6. Limitations

While this review provides a comprehensive synthesis of SDI research, several limitations should be noted. First, the language coverage is primarily restricted to English and Chinese literature, which may exclude relevant planning insights from other linguistic regions. Second, although the database selection included major global and regional repositories (e.g., Web of Science and CNKI), certain official planning documents, policy guidelines, and internal technical reports—which are instrumental in China's territorial spatial planning—may not be fully indexed in peer-reviewed academic databases. Third, the transferability of China-specific concepts, such as "Main Functional Zones," to international contexts remains complex due to divergent land ownership systems and administrative structures. Future research should prioritize cross-national comparative studies to evaluate the global applicability of these SDI frameworks.

Conflicts of Interest

The authors declare no competing interests.

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