Development Pathways of Spatiotemporal Information-Empowered Territorial Spatial Planning

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Abstract: In recent years, spatiotemporal information technologies—including Earth observation, spatial positioning, and GIS—have made significant strides, playing a crucial role in advancing the technological progress and digital transformation of China's planning sector. However, the potential of spatiotemporal information to empower territorial spatial planning (TSP) remains underutilized, characterized by a limited understanding of enabling mechanisms and a lack of advanced, efficient technological toolkits and comprehensive scientific data resources. In the face of nationwide digital transformation and the wave of artificial intelligence (AI), it is imperative to strengthen research and practice in spatiotemporal information-empowered TSP. This requires a paradigm shift toward evidence-based decision-making driven by spatiotemporal data, three-dimensional spatial analysis, and spatiotemporal knowledge, thereby supporting the "digital-intelligent" development of TSP. To this end, this paper proposes an innovation and application trajectory centered on comprehensive digital representation, dynamic analysis, intelligent simulation, and knowledge-based services. Near-term priorities include developing ready-to-use spatiotemporal data products, building specialized analytical platforms, creating operational knowledge services, establishing intelligent public participation mechanisms, and developing specialized methodologies. Furthermore, it is essential to reinforce top-level design, improve support systems, and promote application demonstrations.

Keywords: Spatiotemporal information; Spatiotemporal empowerment; Territorial spatial planning; Development pathway

1. Key Enabling Roles

Broadly defined, territorial spatial planning encompasses three major components: territorial spatial research, territorial spatial planning (formulation), and territorial spatial design. Each of these requires a foundation of spatiotemporal data, support from analytical tools, and guidance from professional knowledge. Under the influence of intelligent technologies, we must reshape the "research-planning-design" paradigm by enhancing "spatiotemporal empowerment" to realize evidence-based, 3D-oriented, and knowledge-driven decision-making (Figure 1).

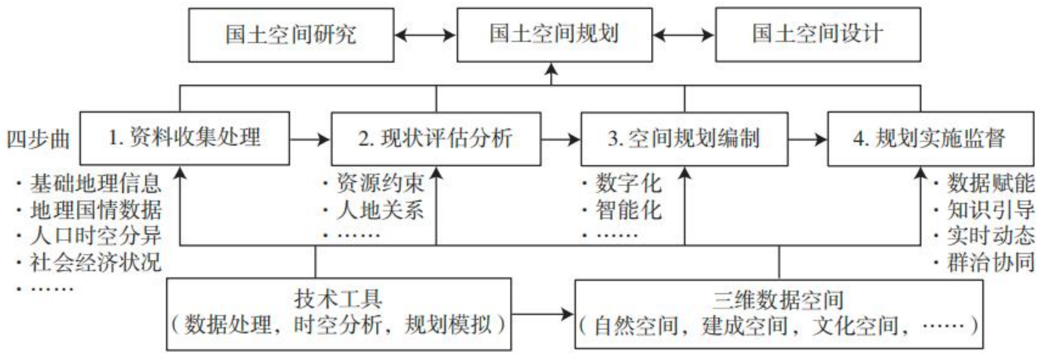

Fig.1 Key steps of territorial spatial planning

1.1 Evidence-Based Decision-Making via Spatiotemporal Data

Acquiring high-quality spatiotemporal information is critical for scientific planning. This involves integrating multi-source data—including remote sensing imagery, fundamental geographic information, and socio-economic data—to construct a foundational dataset. During the "status evaluation" phase, GIS-based spatiotemporal modeling helps evaluate carrying capacity, disaster risk, and human-land relationships, providing a basis for delineating "three zones and three lines." During implementation, IoT and remote sensing enable full-lifecycle monitoring and management. In the future, the fusion of AI algorithms and spatiotemporal data will further enhance the precision and intelligence of planning.

1.2 Analysis and Judgment in 3D Space

As China accelerates the construction of "Real-Scene 3D China" and integrated "air-space-ground-sea" perception systems, planning is shifting from traditional 2D flat surfaces to 3D spatial research. 3D models allow for the simulation of ventilation corridors, view sheds, and sunlight obstruction, providing stereo-based decision support for architectural height and floor area ratio (FAR) validation. Furthermore, immersive 3D scenarios offer new avenues for public participation, enabling stakeholders to intuitively grasp the impacts of planning proposals on their living environments.

1.3 Knowledge-Driven Decision-Making

TSP is a complex endeavor involving social, economic, ecological, and cultural factors. To transition from data-driven to knowledge-guided decision-making, we must distill the vast experience accumulated in planning practice. By employing structured modeling and association techniques, we can mine spatiotemporal knowledge to construct large-scale knowledge graphs. Integrating human intelligence with AI-driven spatiotemporal intelligence systems will enable sophisticated services—including descriptive, diagnostic, predictive, and prescriptive (solution-oriented) support—throughout the entire planning cycle.

2. Overall Development Strategy

Technologically, spatiotemporal empowerment aims to build a comprehensive data foundation, track developmental trends, analyze the evolutionary mechanisms of the territorial spatial "mega-system," and provide scientific cognition for spatial governance. As illustrated in Figure 2, this involves four pillars:

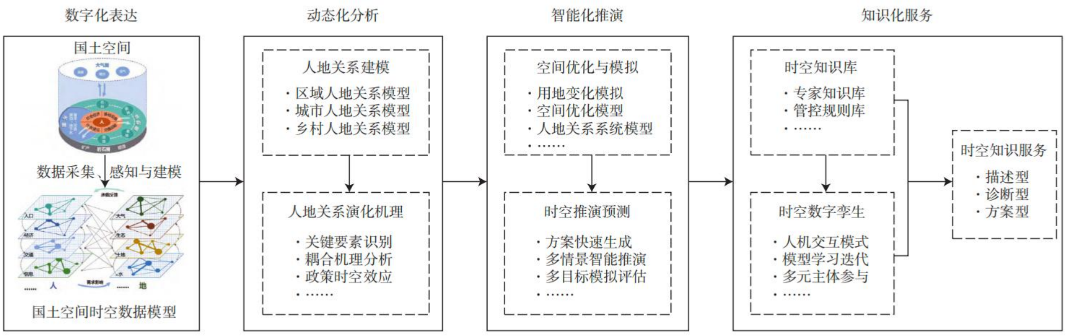

Fig.2 The overall framework of spatiotemporal information-empowered territorial spatial planning

Comprehensive Digital Representation: Constructing a unified spatiotemporal data foundation by integrating "land/resource" factors (natural/built environment) and "human" factors (social activities).

Dynamic Analysis: Quantifying human-land relationships (Figure 3) across multiple scales—from regional ecological carrying capacity to urban functional layout and community-level service accessibility—to reveal the mechanisms of human-environment interactions.

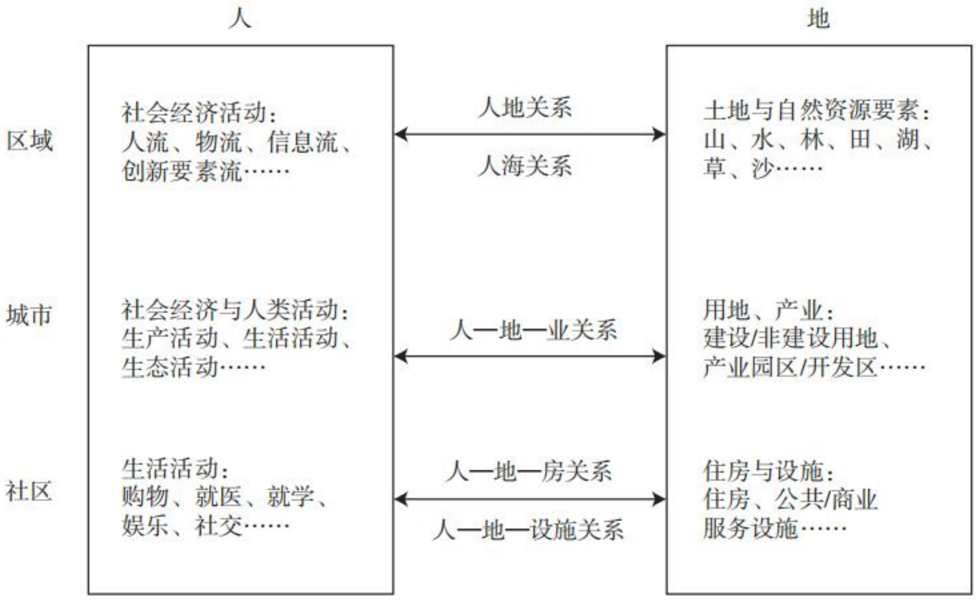

Fig.3 The illustration of territorial planning-oriented human-environment relationship

Intelligent Simulation: Breaking through the limitations of current analytical capabilities by developing 3D-based spatiotemporal intelligent simulation methods. This involves using AI to generate and evaluate multiple planning scenarios under various policy conditions.

Knowledge-Based Services: Establishing a spatiotemporal knowledge base and a "digital twin" of the territorial space to enable real-time simulation, virtual-real interaction, and proactive governance.

3. Key Near-Term Tasks (Figure 4)

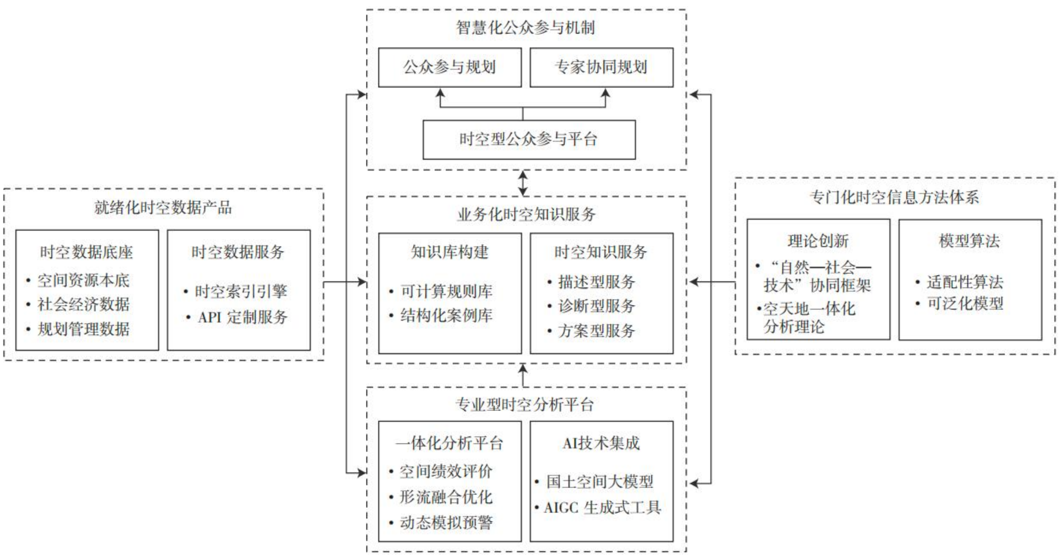

Fig.4 Key near-term tasks

Ready-to-Use Spatiotemporal Data Products: Consolidating natural resource survey data, real-scene 3D models, and socio-economic flow data into a unified, on-demand service architecture.

Specialized Analytical Platforms: Building integrated platforms for "analysis-simulation-warning" that incorporate spatial performance evaluation and AI-driven generative tools (AIGC).

Operational Knowledge Services: Translating planning regulations into computable rules and structuring historical planning cases to provide scenario-based, diagnostic, and solution-oriented services.

Intelligent Public Participation: Developing platforms that dynamically collect and analyze public and expert opinions to generate "demand heatmaps," facilitating a collaborative governance mechanism among government, enterprises, and society.

Specialized Methodologies: Promoting interdisciplinary cooperation to innovate theoretical frameworks—such as the "Nature-Society-Technology" synergy—and developing adaptive algorithms that account for the heterogeneity and complexity of territorial systems.4. Conclusion

Promoting the deep integration of spatiotemporal information with territorial spatial planning is an urgent requirement for achieving a "perceivable, learnable, well-governed, and self-adaptive" spatial planning system. By strengthening top-level design and pursuing the aforementioned technical and methodological innovations, we can drive the "digital-intelligent" transformation of China's territorial spatial governance, ensuring that planning remains scientific, strategic, and authoritative in the new era.

(Note: References [1-77] omitted for brevity, adhering to the original structure and citation placement requirement.)

（AI 辅助翻译）