A Spatiotemporal Empowerment Framework for China’s National 3D Mapping Program 3dRGLM

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Keywords: 3d Realistic Geospatial Landscape Model, Geospatial Entity, Spatiotemporal Perception, Spatiotemporal Connection, Spatiotemporal Computing, Spatiotemporal Intelligence.

Abstract

China has launched a national 3D mapping program to build 3D Realistic geospatial Landscape Model (3dRGLm) over the whole country, covering both cities and countryside. The 3dRGLM is a digital description and representation of the real 3D geospatial spaces, and is defined as a new generation geospatial data product with 3D structures, realistic scenes, and geospatial entities. Such a national or local 3dRGLm will set up a digital 3D realistic geospatial space which can facilitate the vital connection with the real geospatial space, and will serve as a new generation of geospatial information infrastructure for our society. With the acquisition of complex 3D spatial data continues to advance, managing and utilizing the massive volumes of 3D data to provide spatiotemporal empowerment applications has become a significant technological challenge. This paper analyzes the technical characteristics of 3d realistic geospatial landscape model, and then proposes the main content and basic structure of a 3d realistic geospatial landscape model database, as well as the spatiotemporal service empowerment methods based on the database. Finally, a case analysis is provided to serve as a reference for the construction and application of 3d realistic geospatial landscape.

1. Introduction

Currently, countries around the world are vigorously promoting digital development and high-quality growth, advancing the construction of digital economy, digital governance, digital culture, digital society, and digital ecological civilization. This drives comprehensive and profound transformations in production, living, and governance methods, thereby generating new demands for the products and services of fundamental surveying and mapping. On one hand, all high-quality development occurs within a geospatial context, relying on the high-quality operation of activities within this space. The integrative, spatial, and continuous characteristics of these activities exhibit significant spatiotemporal features. Spatiotemporal information plays an irreplaceable role in condition assessment, environmental investigation, status monitoring, process insight, trend forecasting, effectiveness tracking, and innovative model reshaping under conditions of high-quality development. On the other hand, the internal and external environment of the current surveying and mapping geographic information industry, its products, production service models, and knowledge systems have undergone substantial changes. Spatiotemporal information technology, while supporting digital development and enabling high-quality growth, still faces numerous challenges. High-quality development imposes new requirements on the precision, temporal frequency, and service methods of spatiotemporal information. There is an urgent need to provide high-quality spatiotemporal information, support advanced spatiotemporal analysis, and implement high-level spatiotemporal empowerment.

We live in a multidimensional, dynamic real world. However, in the past, people abstracted this reality into two-dimensional, static targets using planar map-raster models, essentially performing 2 to 2.5-dimensional modeling. In today's era of comprehensive digital transformation, many intelligent applications require observation, measurement, analysis, and simulation within three-dimensional digital spaces to achieve real-time interconnection and interoperability between digital and real spaces. Advancing spatiotemporal information from 2 to 2.5-dimensional products to multidimensional dynamics, enabling communication through spatiotemporal information, conducting assessments in three-dimensional spaces, and making decisions based on spatiotemporal knowledge is the trend of the times. This has also become a widespread consensus among governments and industry. In fact, significant advancements in spatiotemporal information technology have been made in recent years. Core technologies such as remote sensing, positioning, and geographic information systems have deeply integrated, substantially enhancing the spatiotemporal accuracy of Earth observations. Techniques have evolved from macro-scale global observations to precise canopy-scale observations, significantly improving our ability to perceive, understand, and manage our environment(Chen et al. 2016; Kok and Van Loenen 2005; Li and Lu 2018).

Since the 1990s, the international academic community has begun exploring multidimensional geographic information modeling and applications. The International Society for Photogrammetry and Remote Sensing (ISPRS) has identified 3D modeling and processing, as well as multidimensional dynamic GIS, as encouraged research areas (Li 1994; Koehl & Grussenmeyer 1998; Zlatanova et al. 2004). Recently, ISPRS released its 2022-2026 encouraged research areas, emphasizing the need to strengthen exploration in multidimensional and semantic data modeling, spatial analysis, and advanced visualization (Chen et al. 2022). A review of the themes and strategic objectives of ISPRS conferences and the International Conference on 3D Geoinformation over the past 20 years reveals that the transition of GIS from two-dimensional to three-dimensional and from static to dynamic is an inevitable trend. There is an internationally unified consensus on the importance of research in 3D dynamic geographic information modeling and applications. Concurrently, the provision of high-quality spatiotemporal information, advanced geospatial computing capabilities, and collaborative decision support constitutes the primary technological needs for the present and foreseeable future.

Three-dimensional mapping has extensive applications in sustainable development, as it can help people better understand and address complex issues in this field (Hogg et al. 2018). 3D mapping can aid in monitoring and assessing the sustainable use of natural resources. For instance, it can evaluate forest, water, and land use, and predict the impacts of different management schemes on biodiversity, water resources, and land health (Guang et al. 2023; Davies and Asner 2014; De et al. 2019). This helps in protecting natural ecosystems, rationally utilizing natural resources, and promoting ecological restoration. In geological disaster simulation analysis and climate change impact analysis, multidimensional spatial information can help predict potential risk areas and assess the effectiveness of disaster prevention measures. This enhances emergency response capabilities and the sustainability of post-disaster reconstruction, playing a crucial role in disaster prevention and management (Bandrova et al. 2012; Li et al. 2021a; Li et al. 2021b).

In the construction of digital cities, the creation of virtual city models is carried out in three-dimensional spaces(Holland and Allan 2001; Nebiker et al. 2015; Soon and Khoo 2017). Digital city planning is now widely practiced globally, and 3D visualization can assist decision-makers in evaluating the feasibility and impacts of urban development plans (Chen 2011; Singh et al. 2013; Bremer et al. 2016). It can simulate the effects of different development plans on the environment, traffic, energy use, and social equity, thereby helping to formulate more sustainable urban planning strategies. Based on 3D mapping data, integrating multi-source ubiquitous data facilitates the fusion of multidimensional information on natural resources, geographical environments, and socio-economics. This supports various natural resource management applications such as farmland protection, resource supervision, ecological restoration, and land planning. Furthermore, to meet the needs of digital economy, digital society, and digital government activities, observing, measuring, analyzing, and evaluating in three-dimensional digital spaces is an inevitable trend in digital development(Fridhi and Frihida 2019; Gagnon and Coleman 1990; Reid et al. 2010). To meet the urgent demand for spatiotemporal information driven by digitalization and high-quality development, China has launched a national 3D mapping program to build 3D Realistic Geospatial Landscape Model (3dRGLm) over the whole country, covering both cities and countryside(Jun et al. 2022). The 3dRGLM is a digital description and representation of the real 3D geospatial spaces, and is defined as a new generation geospatial data product with 3D structures, realistic scenes, and geospatial entities. Such a national or local 3dRGLm will set up a digital 3D realistic geospatial space which can facilitate the vital connection with the real geospatial space, and will serve as a new generation of geospatial information infrastructure for our society(Chen et al. 2022; Gao et al. 2024; Jun et al. 2023). With the acquisition of complex 3D spatial data continues to advance, managing and utilizing the massive volumes of 3D data to provide spatio-temporal empowerment applications has become a significant technological challenge.

This paper analyzes the technical characteristics of the 3dRGLm and proposes the core content and fundamental structure of a 3dRGLm database. Furthermore, a case analysis is presented for the development and application of 3dRGLm, as well as the spatio-temporal service empowerment approaches.

2. Method

2.1 Basic Characteristics of 3dRGLm

Aiming at the nationwide digitalization of society, this new concept of spatiotemporal information, characterized by three fundamental features—stereoscopic, realistic, and substantive—addresses the need for the digital representation of the three-dimensional structure and apparent texture of natural and human phenomena within the national territory, as well as the effective integration and shared utilization of various socio-economic-environmental information.

The stereoscopic aspect refers to the use of 3D modeling technologies to present elements such as terrain, buildings, vegetation, and underground spaces to users, thereby providing a more three-dimensional map experience. Currently, the stereoscopic representation in real-scene 3D can achieve high precision and resolution. The realistic aspect involves generating models through real-scene 3D technology that align with the real world, creating highly realistic scenes, including the surface and structures. The substantive aspect means that the generated model objects occupy a continuous spatial position and range in the real world, possessing the same attributes or complete functions independently. This enables the effective integration of various socio-economic-environmental information, promoting comprehensive societal sharing and utilization.

Overall, 3dRGLM products can authentically, stereoscopically, and temporally reflect human production, living, and ecological spaces, achieving real-time interconnection between digital and real spaces. This provides a new generation of spatiotemporal information base for Digital China, establishing spatiotemporal associations among various fundamental geographic, natural resource, and socio-economic information. It helps break down data silos formed by industry, region, and other factors, driving the interconnection of all things with spatiotemporal information and supporting the efficient flow of data elements. Through the construction of real-scene 3D, we can create a more stereoscopic and realistic national spatial environment in the digital age, opening up new possibilities for future societal development.

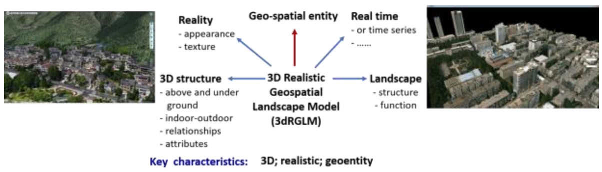

Figure 1. The overall architecture of the 3dRGLm

2.2 The Typical 3dRGLm Data Product

The data product system of 3dRGLm is based on a unified spatiotemporal reference framework and comprises existing 4D products and novel data products. Leveraging digital and intelligent mapping technologies, the Real-Scene 3D data products create a three-dimensional digital space that effectively represents the terrain, natural features, man-made structures, and management units of the real world. This digital space, characterized by geospatial entities, Geospatial Landscapes, and geospatial realistic scenes, accurately describes the state and dynamic changes of these elements.

2.2.1 Geospatial Entity Products: To aid in the understanding of various natural and human phenomena on the Earth's surface, historically, land features were abstracted into terrain elements and described using vector models such as points, lines, and polygons. Taking the national 1:50,000 scale fundamental

https://doi.org/10.5194/isprs-archives-XLVIII-4-2024-205-2024 |

geographic information data as an example, natural and man-made objects were categorized into 9 major classes and over 470 subclasses. A geographic entity refers to objectively existing features in the real geographic world that have spatial locations and can be distinguished from each other. This concept involves the unified modeling, digital description, and semantic expression of different types of Geospatial entities, including natural, artificial, and management entities. Geospatial entity products are objectified models of geographic objects in the real world, representing their various spatial forms and full life cycles. These products reflect and express information such as the spatial distribution, relationships, attribute characteristics, temporal features, and coding methods of geographic objects. They belong to the category of substantive and semantic information, which can be queried, statistically analyzed, mined, and linked with various socio-economic information, serving as spatiotemporal hubs for information aggregation and integration. Notably, the expression of Geospatial entities is more diverse. They can be formed into two-dimensional entities through the objectification transformation, semantic upgrading, thematic combination, and aggregation of existing basic mapping DLG products. Alternatively, they can be formed into three-dimensional entities through model transformation, data fusion, and information linkage based on 3D modeling products (such as individual models and component models).

2.2.2 Geospatial Landscape Products: Geographic environments possess unique apparent texture information, serving as the original information source for spatial perception. Traditionally, digital images captured from aerial or satellite photography underwent planar mapping, differential correction, and mosaicking to create digital orthophoto maps (DOMs), which combine map geometric accuracy with image characteristics. These DOMs use continuously arranged two-dimensional pixels to record high-precision, visually realistic surface texture information, meeting users' needs for geographic environment perception. Geographic scenes provide a three-dimensional and intuitive description of objectively existing natural or human landscapes in the real geographic world. They use continuously arranged three-dimensional voxels to record digital scenes that align with the real world, creating highly realistic scenes that can more accurately and intuitively describe and express the three-dimensional geographic environment. Geospatial Landscape products are spatial data products formed through the integrated modeling, digital description, unified storage, and realistic expression of regional topography and urban surfaces. These products focus on expressing information such as terrain relief and surface textures of urban features, accurately describing the real world. They are directly used for 3D browsing, spatial measurement, stereoscopic analysis, and as base layers for overlaying other data, thereby better meeting users' needs for spatial perception of the geographic environment.

2.2.3 Dynamic Landscape Scene Products: Dynamic landscape products are dynamic real-scene products that integrate geographic entity and scene products, dynamically incorporating real-time information such as IoT sensing, socio-economic data, and spatiotemporal trajectories. These products achieve integrated storage and fused expression of Geospatial entities and scenes in both vector and raster forms. Depending on the scale of expression, they can be divided into terrain real-scene products, urban real-scene products, and component real-scene products. Terrain real-scene products are composed of macro and meso geospatial entities and terrain scene products, supporting intuitive perception and cognition of large-area geographic environments and objects, with a focus on the digital mapping of ecological spaces. They form the foundational basis for city-level and component-level real-scene data products. Urban real-scene products are composed of meso and micro geographic entity products and urban scene products, dynamically integrating urban IoT sensing data. They focus on the perception and cognition of urban spatial geographic environments and objects, with an emphasis on the digital mapping of production and living spaces.

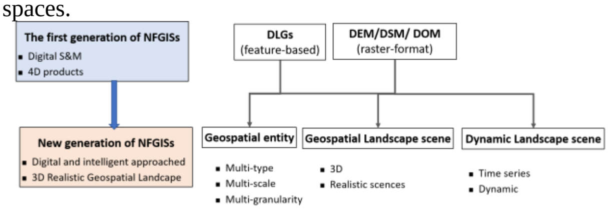

Figure 2. The Typical 3dRGLm Data Product

2.3 General Framework of 3dRGLm Database

3dRGLm is oriented towards the comprehensive digital transformation of the entire society with the nation as the object. It comprehensively considers the digital expression of the stereoscopic structure and textural appearance of natural and human phenomena within the national territory, as well as the effective integration and shared utilization of various social, economic, and environmental information. 3dRGLM is a digital description and representation of the real 3D geospatial spaces, and is defined as a new generation geospatial data product with 3D structures, realistic scenes, and geospatial entities. Such a national or local 3dRGLm will set up a digital 3D realistic geospatial space which can facilitate the vital connection with the real geospatial space, and will serve as a new generation of geospatial information infrastructure for our society.

Currently, traditional spatial databases are unable to meet the management and service application requirements of 3dRGLm data. To construct a new 3dRGLm database, it is necessary to achieve two key objectives: the physicalization management of realistic 3D data entities and the provision of spatio-temporal empowerment services. The physicalization management of 3dRGLm data entities involves the comprehensive digitization, modeling, and integration of various geographic elements, including terrain, buildings, vegetation, transportation, and other infrastructure, to form a complete and accurate 3D digital twin of the national territory. The spatio-temporal empowerment services based on the 3dRGLm database aim to provide efficient observation, measurement, analysis, and simulation capabilities for the 3D digital space, supporting a wide range of applications in urban planning, environmental monitoring, disaster response, and national security, among others.

The key to the physicalization management of 3dRGLm data entities is the construction of a 3dRGLm database centered on entities. By organically connecting various Geospatial entities, scenes, and realities through entity objects, the physicalization management of the data can be achieved. Furthermore, by associating the entities with social, economic, environmental, and Internet of Things (IoT) sensing information, a spatio-temporal big data information platform based on 3dRGLm can be constructed, enabling ubiquitous big data interconnectivity. The general framework of the 3dRGLm geospatial entities database and entity relationship data is shown in Figure 3 and Figure 4.

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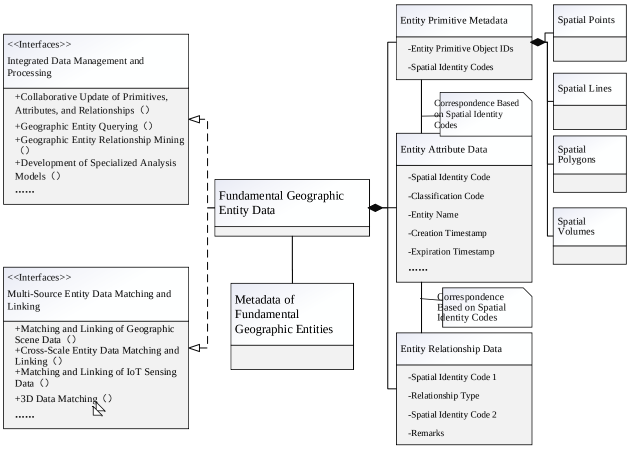

Figure 3. Conceptual Model of Fundamental Geospatial Entities Database

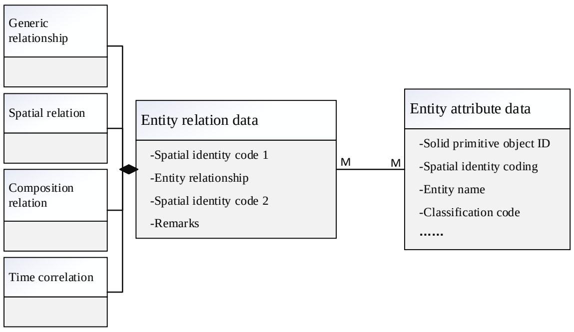

Figure 4. Conceptual Model of Entity Relationship Data

2.4 Service enabling framework of the 3dRGLm

Based on the 3dRGLm data products, services are provided through the National Geographic Information Public Service Platform and the National Territorial Space Basic Information Platform. This enables the real-time aggregation, integration, and computation of 3dRGLm with ubiquitous information on society, economy, population, and natural resource management. A collaborative and shared positive ecosystem is thereby established, creating a 3dRGLm service empowerment system characterized by horizontal sharing and collaboration and vertical real-time interaction.

Starting from the foundational logic of spatiotemporal empowerment, this study conducts a comprehensive and systematic analysis of the mechanisms and implementation pathways of spatiotemporal empowerment. It explores the methods of spatiotemporal empowerment along the main lines of spatiotemporal perception, spatiotemporal connectivity, spatiotemporal computing, and spatiotemporal intelligence.

Spatiotemporal information has significant potential to empower digital development and high-quality development. By providing ubiquitous spatiotemporal perception, pervasive spatiotemporal connectivity, continuous spatiotemporal computing, and comprehensive spatiotemporal intelligence, the value and role of spatiotemporal information can be fully realized. This, in turn, will effectively promote deep, high-level applications and achieve high-quality development empowered by spatiotemporal information.

2.4.1 Spatiotemporal Perception: Spatiotemporal perception primarily refers to the use of sensors or devices to observe and process data on the distribution, structure, quality, and changes of regional land surfaces, urban spaces, or indoor and outdoor micro-scenes. In recent years, the rapid development of technologies such as remote sensing satellites, UAV aerial photography, the Internet of Things (IoT), and the Visual Internet has significantly enhanced the capabilities for large-scale rapid coverage and spatial perception using high spatial resolution imagery. Spatiotemporal perception primarily refers to the use of sensors or devices to acquire data on the distribution, structure, quality, and changes of regional surfaces, urban spaces, or indoor and outdoor micro-scenes through observation and processing. Given that natural changes or human activities often exhibit specific spatial and temporal characteristics, using a real-scene 3D digital space as an information integration platform can facilitate the construction of widely perceptive collaborative and spatial observation models.

2.4.2 Spatiotemporal Connection: Spatio-temporal connection provides a unified geographic spatial framework to effectively associate various information within the national territory, enabling integrated modeling and comprehensive expression. This forms a digitally-twinned national territory with full-domain coverage and multi-scale, laying the foundation for spatio-temporal computation and intelligence.

Spatiotemporal connection provides a unified geospatial framework that effectively links various types of information within the domain of territorial space. This facilitates integrated modeling and comprehensive representation, forming a digitally comprehensive territorial space with diverse scales, thus laying the foundation for spatiotemporal computing and spatiotemporal intelligence. In the grand architecture of "Digital China," 3D spatiotemporal information is akin to the three-dimensional structural framework of a building. Traditionally, the connection of cross-domain information through spatiotemporal relationship calculations or spatial position matching has faced challenges such as time consumption, labor intensity, and poor timeliness, making automated information connection difficult. However, the core product of Real-Scene 3D China, "Geospatial entities," precisely addresses the growing demand for high-quality spatiotemporal information across various sectors in the new era and is poised to become the intelligent data foundation of Digital China.

2.4.3 Spatiotemporal Computation: Spatiotemporal computation relies on algorithms and computational power to support the real-time invocation and effective combination of various algorithms, enabling the processing of massive spatiotemporal big data. This, in turn, uncovers and realizes the potential value of spatiotemporal data as a production factor. Spatiotemporal information is characterized by vast volumes, specialized processing, and frequent updates. With the advent of the era of the Internet of Everything and spatiotemporal connectivity, the volume of spatiotemporal information is rapidly increasing, and high-level spatiotemporal analysis and diversified spatiotemporal scenario applications are emerging continuously. Spatio-temporal computation leverages algorithms and computing power to support the real-time invocation and effective combination of various algorithms, enabling the computational processing of massive spatio-temporal big data. This helps to unlock and realize the potential value of spatio-temporal data as a factor of production.

2.4.4 Spatiotemporal Intelligence:

The core of spatiotemporal intelligence lies in the deep integration of natural intelligence and artificial intelligence, enhancing the autonomous behavior capabilities of entities. This allows them to design and execute governance schemes through self-supervised or even unsupervised methods, thereby optimizing governance strategies, fulfilling governance tasks, and improving governance performance. Spatiotemporal intelligence is based on high-quality spatiotemporal information and can achieve spatiotemporal perception, cognition, and computation through the "comprehensive, complete, holographic, and dynamic" isomorphic mapping of the real world and the digital world, coupled with spatiotemporal big data analysis and artificial intelligence algorithms.

3. Results

To validate the feasibility of constructing the 3dRGLm database, technical experiments and application verification were conducted based on a huge amount of 3dRGLm data from the National Geomatics Center of China. The spatio-temporal empowerment services are based on a widespread, cloud-interconnected spatio-temporal information computing infrastructure. Through spatio-temporal perception, connection, computation, and intelligence, they achieve high-quality spatio-temporal information supply, high-level spatio-temporal analysis, and high-level spatio-temporal empowerment, and carry out a variety of applications(Jun et al. 2023).

3.1 Spatiotemporal Perception and Typical Application scenarios

Collaborative observation leverages technologies such as collaborative mission planning, multi-satellite joint imaging, aerial networked observation, IoT sensing integration, and crowdsourced discovery (Figure 5). These technologies organically integrate satellite, aerial, ground, and network data observation methods within target areas as needed, forming a highly efficient, collaborative, real-time transmission, and stereoscopic perception monitoring network that combines macro and micro perspectives as well as point and surface integration. Spatial observation employs techniques such as data matching, spatiotemporal mapping, scene correction, and stereoscopic fusion to integrate and render various heterogenous sensing information deployed widely and interconnected via the cloud within the real-scene 3D digital space. This creates a real-time data perception capability that operates synchronously with the real world.

Utilizing collaborative and spatial perception to organically integrate multimodal sensing methods and achieve spatiotemporal integration helps aggregate shareable resources across regions and industries to form a synergistic force. This, in turn, facilitates the creation of a seamless spatial, continuous temporal, comprehensive, and stereoscopic perception network that covers all regions and time domains. For instance, by constructing an integrated monitoring network for natural resources encompassing "sky, ground, and network," a positive governance mechanism can be established that enables early detection, early warning, and early response to issues.

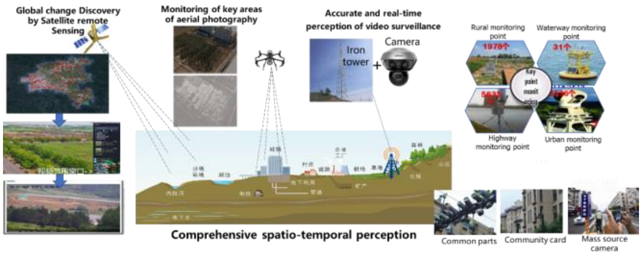

Figure 5. IoT Information Fusion Based on 3dRGLm

3.2 Spatiotemporal Connection and Typical Application scenarios

Geospatial entities employ techniques such as unique identification, integrated expression, and incremental updates, providing common anchor points for cross-domain and cross-business information linkage. This promotes the deep integration of spatiotemporal information with socio-economic-resource-environment big data, facilitating comprehensive utilization and sharing across society. For example, using Real-Scene 3D China as the foundational base and geographic entity spatial identity codes as the linkage, spatiotemporal associations can be established among natural resource entities, real estate entities, territorial space planning elements, and ecological environment elements. This enables the seamless connection of the entire business chain of natural resources, promoting the optimized allocation of natural resources in both time and space.

Therefore, efforts should be made to construct a spatiotemporal data governance model centered on geospatial entities, advancing spatiotemporal big data from aggregation to computability. This involves establishing a ubiquitous and general spatiotemporal big data cross-domain interoperability paradigm, addressing the challenge of deep integration between spatiotemporal information and socio-economic-resource-environment big data through entity connection and isomorphic mapping (Figure 6). It is worth noting that socio-economic activities possess inherent complexity. Thus, it is essential to vigorously promote the collaborative construction and cross-regional interactive maintenance of Geospatial entities across departments, fostering a shared ecosystem. Through the integration and circulation of spatiotemporal big data elements, a digital twin system for high-quality development can be established.

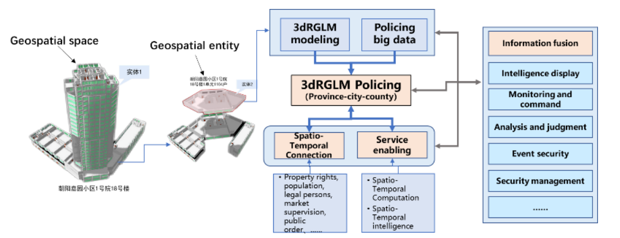

Figure 6. 3dRGLm Policing Based on Spatiotemporal Connection

3.3 Spatiotemporal Computation and Typical Application scenarios

To address this, it is essential to innovate in both computational power and algorithms based on interconnected spatiotemporal big data, thereby constructing a spatiotemporal computing infrastructure that is always available. Firstly, addressing the critical bottlenecks of traditional centralized computing platforms, such as the difficulty in expanding computational power and sharing algorithms, new technologies such as dynamic service computing and platforms should be comprehensively utilized. This involves researching and constructing a standardized, intensive, and specialized dynamic service computing platform for spatiotemporal information, enabling cross-domain sharing and collaborative interaction between systems, and building a computational power infrastructure that effectively supports spatiotemporal information computing.

Secondly, to meet the new demands for three-dimensional scene computation, spatiotemporal analysis, simulation and assessment, and knowledge mining, it is necessary to leverage the open ecosystem of the dynamic service computing platform. This will gather and form an algorithm toolbox and operator model library suitable for real-scene 3D analysis, providing end users with low-threshold, generalized spatiotemporal computing capabilities required for their business needs. For example, current mainstream GIS software includes over 170 spatial analysis operators related to 3D, which, despite rapid development in recent years, still lags behind the over 300 operators available for 2D spatial analysis, indicating room for further growth. By innovating key technologies, valuable spatiotemporal knowledge can be extracted from massive spatiotemporal data, thereby better serving users with data-information-knowledge services (Figure 7).

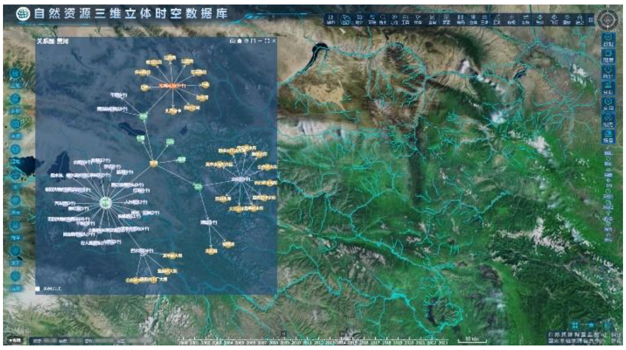

Figure 7. Knowledge Graph Representation based on Spatiotemporal Computation

3.4 Spatiotemporal Intelligence and Typical Application scenarios

The core of spatio-temporal intelligence is the deep integration of natural and artificial intelligence, which enhances the autonomous behavior capabilities of entities(Chen et al. 2022). This allows them to design and execute governance solutions through self-supervised or even unsupervised means, thereby optimizing governance approaches, completing governance tasks, and improving governance performance.

For example, based on the real-time interconnection between real-scene 3D digital space and real geographic space, spatiotemporal monitoring, feedback, regulation, and services can be carried out. Problems can be identified in the 3D digital space, solutions proposed, and then fed back to the "physical space" of the real world and the "social space" of human activities, thus realizing intelligent applications under informatized conditions. In fact, artificial intelligence is a theoretical method and technology that simulates, extends, and expands human intelligence, but general artificial intelligence algorithms are not directly applicable to spatiotemporal data analysis. Therefore, it is essential to actively promote theoretical and technological innovations in the intelligence of spatiotemporal information (Figure 8).

From a theoretical perspective, spatial expansion of artificial intelligence algorithms should be considered, incorporating spatiotemporal positions, distributions, and change characteristics, striving to form artificial intelligence technologies and knowledge engineering with spatiotemporal features. This would be used for intelligent spatiotemporal analysis and knowledge services of multi-source heterogeneous data. From a technological perspective, constructing a computational framework suitable for spatiotemporal intelligence should be considered, integrating key technologies such as spatiotemporal memory, spatiotemporal reasoning, and spatiotemporal learning. Developing a spatiotemporal intelligent computing engine would support real-time perception, dynamic modeling, cognitive computing, intelligent expression, and knowledge services of spatiotemporal information. In other words, with the aid of spatiotemporal intelligence, it is expected to solve the development dilemma of "massive data, information explosion, and difficult access to knowledge" that exists in reality.

Figure 8. Low Airspace Intelligence Navigation and Drone Delivery Route Planning Based on 3dRGLm

4. Discussion and Conclusion

Although surveying and mapping geographic information have reached countless households, and digital surveying products and services have gradually permeated various aspects of the digital economy, digital governance, and digital life, becoming essential spatiotemporal infrastructure and foundational information for production factors, their overall potential has yet to be fully realized. The integration with socio-economic sectors remains insufficient, making fusion and innovation imperative.

Digital economy, digital governance, digital life, digital culture, and digital ecological civilization are all closely related to spatiotemporal information. Therefore, it is crucial to vigorously promote the deep integration of Real-Scene 3D China with the "Five-in-One" framework. This would facilitate the rapid, precise, and intelligent matching and efficient circulation of various production factors in spatiotemporal contexts, leading to the reconstruction of production models, transformation of lifestyles, and intelligent urban-rural governance. Ultimately, this will promote a green and low-carbon transition of the economy and society.

To ensure the continuous and steady advancement of Real-Scene 3D China construction and application, it is essential to enhance strategic analysis and research, promote key technological innovations, and facilitate cross-sector integration and convergence.

(1) Strengthening Strategic Needs Analysis: The concept of Real-Scene 3D China is novel and rich in connotation. Its in-depth research, successful construction, and widespread application will drive theoretical and technological innovations in digital development and high-quality growth. Adhering to the spirit of inheritance and development, it is essential to innovate scientific concepts through the process of practice-recognition-repractice-rerecognition, clarify technical logic, and develop and construct a knowledge system of Real-Scene 3D China with inherent logic and structure, as well as explanatory and persuasive power. This system should promote the integration of knowledge and application, supporting national and local engineering practices effectively.

Based on this foundation, according to the national strategic needs and the urgent requirements of national and local construction applications, and following the principles of "overall planning, collaborative construction, and phased advancement," it is necessary to elucidate the technical implementation pathways for Real-Scene 3D construction at different levels—national, provincial, and municipal. This includes proposing phased technological innovation tasks and suggesting supporting measures such as resource integration and policy guarantees to meet current urgent needs while considering future development.

(2) Promoting Key Technological Innovations: Scientific and technological innovation is boundless. Constructing a new development paradigm and achieving high-quality development rely on high-level scientific and technological self-reliance and self-strengthening. Real-Scene 3D China represents both a novel concept and encompasses new products and technologies. It addresses significant national and local demands and is a prominent research topic in the international scientific community. Advancing its high-level, intelligent applications is a formidable task.

Therefore, it is crucial to develop a digital and intelligent technological system for Real-Scene 3D China through a series of technical methods, including physical modeling, three-dimensional reconstruction, realistic description, and knowledge-based services. This system should encompass corresponding production processes, software tools, service platforms, and standard specifications, thereby effectively supporting national and local engineering construction and application practices.

Subsequently, leveraging Real-Scene 3D China as a pivotal element, and adhering to the "Four Orientations," it is essential to foster innovation, strengthen interdisciplinary scientific and technological problem-solving, and promote positive collaboration among industry, academia, and research institutions. This collective effort will advance the depth and substance of Real-Scene 3D construction, addressing urgent needs in the digital economy, digital life, and digital governance. On the new journey of Chinese modernization, it will tell the story of how spatiotemporal information empowers high-quality development in China.

(3) Facilitating Cross-Disciplinary Integration: Real-Scene 3D China is an exceedingly complex information engineering project, encompassing the entire chain from data to information, knowledge, and wisdom. Thus, interdisciplinary collaboration is imperative. It is essential to intensify the integration of various disciplines and enhance the cooperation among different professional fields (such as land, planning, forestry, geology, marine, and surveying). Furthermore, incorporating expertise from artificial intelligence, the Internet of Things, big data, and related sectors such as geosciences, economics, cultural tourism, civil affairs, water conservancy, construction, and development and reform is crucial. This integration should harness the intellectual resources of multiple departments to generate collective wisdom, complement strengths, and foster coordinated development.

By innovating development concepts and promoting cross-disciplinary integration, we can drive the deep integration of Real-Scene 3D with socio-economic-environmental-industry big data in the context of high-quality (sustainable) development, advancing the "Real-Scene 3D+" initiative. This effort aims to create a new generation of spatiotemporal information infrastructure and promote high-level intelligent applications.
Subsequently, accurately grasping the requirements of the digital economy, digital government, and digital society, Real-Scene 3D China should be incorporated into the broader framework of Digital China construction. Multiple measures should be implemented to unblock the "main artery" of spatiotemporal information service circulation, thereby making a significant contribution to the digital and high-quality development of both the nation and local regions.

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