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Application of New Basic Surveying and Mapping Technology Oriented to the Space Time Database of Smart City

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In response to the emerging demands of smart city and digital city construction, a pressing research frontier and practical necessity is determining how a new basic surveying and mapping technology can better enhance the service functions of geospatial data in smart city development. The "One Map" approach for smart cities serves as a unified spatiotemporal reference framework for the entire city, acting as the digital spatial carrier and common infrastructure for smart cities. In this paper, we review the relationship between the spatiotemporal data framework of smart cities and the new basic surveying and mapping technology, as well as the requirements that the "One Map" approach imposes on such technology. Using Beijing's pilot project as a case study, we introduce the key technologies derived from the new basic surveying and mapping technology to create the "One Map" for smart cities, aiming to provide replicable and scalable experiences for the construction of a national new basic surveying and mapping system and the data frameworks of smart cities.

1. Introduction

Foundational surveying and mapping are critical means for accurately understanding national conditions and strengths. They provide a fundamental basis for professional censuses, scientific decision-making, and the implementation of major national strategies and projects.(1) China has made significant progress in foundational surveying and mapping, with the extensive construction of new basic surveying and mapping systems at both national and local levels,(2–4) offering robust foundational data services to support economic and defense developments. The "National Long-term Plan for Foundational Surveying and Mapping (2015–2030)" has identified a new basic surveying and mapping technology as the direction for transformation and upgrading, aiming to provide higher quality and more efficient geographic information services

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to meet the needs of modern social and economic development. This new basic surveying and mapping technology, by integrating advanced equipment and techniques such as oblique photography, mobile measurement, 3D laser scanning, and big data, achieves efficient, precise, and rapid data collection and processing, providing accurate and real-time geographic spatial information for smart cities. It is a necessary product of the transformation and development of the national economy and a significant opportunity for the cross-domain development of surveying and geographic information.[5–8]

With the rapid development of smart city construction in the new era, the demands of smart cities have further driven the innovation and advancement of new basic surveying and mapping technologies. Many cities in China have developed "One Map" systems for various sectors, such as water resources,[9] land management,[10] and smart transportation.[11] However, these applications often focus on specific professional fields, leading to issues such as incomplete coverage, redundant construction, nonuniform technical standards, and difficulties in aligning outcomes. Since 2018, the Beijing Municipal Government has launched the Beijing Big Data Action Plan to promote the development of Smart City V2.0. The "14th Five-Year Plan" of Beijing further proposes to build a benchmark city for the global digital economy and a model for new smart cities worldwide. After years of accumulating foundational surveying and mapping data, Beijing has developed rich data resources in various areas such as digital city construction, smart city development, the third national land space survey, forest and grassland resources survey, and real estate survey. The Beijing Big Data Platform has collected trillions of data entries from various municipal departments, with data interface calls reaching 1.1 billion times. Currently, Beijing has established a "One Map" system for the entire city, featuring unified base map data, a unified coordinate system, a unified spatiotemporal encoding, and a unified service platform, thereby creating a unified spatiotemporal reference framework for the whole city. By combining digital city and smart city construction techniques, new basic surveying and mapping technologies have gradually enriched aspects such as foundational aerospace remote sensing, foundational geographic information construction, and large-scale data coverage.[12,13] This development addresses the limitations of traditional foundational surveying and mapping products, which primarily rely on two-dimensional data and lack three-dimensional scenes, enhancing data unification and real-time capabilities.[14,15]

In this paper, we review the relationship between the spatiotemporal data framework of smart cities and a new basic surveying and mapping technology. We analyze the requirements that the "One Map" approach imposes on the new basic surveying and mapping technology. Drawing on the construction of the "One Map" system in Beijing's smart city development, we introduce the key technologies used to generate the spatiotemporal data framework for smart cities through the new basic surveying and mapping technology. The goal is to provide valuable insights and references for the construction of a new basic surveying and mapping system at the national level and for smart city development in various regions.

2. Relationship between the Spatiotemporal Data Framework of Smart Cities and New Basic Surveying and Mapping Technology

The spatiotemporal data framework of a smart city refers to a comprehensive data platform that integrates various types of spatiotemporal data within the city, providing essential support for urban management and operations. In March 2021, the Ministry of Natural Resources issued the "Technical Outline for the Pilot Project of New Fundamental Surveying and Mapping," which clarified the top-level design of new fundamental surveying and mapping. In November 2021, the "Control Planning Requirements for Smart City Construction during the 14th Five-Year Plan Period (Trial)" by the Beijing Municipal Government proposed building a common foundational platform for smart cities based on the principle of "seven connections and one leveling." It explicitly stated that the informatization of smart cities must rely on the "One Map" as the foundational platform. On June 15, 2021, Beijing was approved as a pilot city for the construction of a new fundamental surveying and mapping system, incorporating the pilot project into Beijing's efforts to become a benchmark city for smart cities and the digital economy. This initiative was included in the "Task List for Building a Global Digital Economy Benchmark City 2022." The list identified the "One Map" approach for smart cities as standard infrastructure, requiring the creation of a unified digital base that integrates 2D and 3D data, covers aboveground and underground areas, and supports dynamic updates. On June 22, 2022, the Ministry of Natural Resources approved the "Implementation Plan for the Beijing Pilot Project of National New Fundamental Surveying and Mapping Construction," which mandated the development of a universal "One Map" for smart cities. This map aims to provide a unified positioning reference and encoding service, significantly enhancing the service functions of geospatial data in smart city construction.

In summary, the spatiotemporal data framework of smart cities and the new fundamental surveying and mapping technology are complementary. The new fundamental surveying and mapping technology provides the necessary geospatial data support for smart cities, while the demands of smart cities drive the development and application of various new fundamental surveying and mapping technologies.

3. Requirements of the Spatiotemporal Data Framework for New Fundamental Surveying and Mapping Technology

The goal of constructing the "One Map" for smart cities is to enhance coordination and resource integration and create a unified digital base that integrates 2D and 3D data, covers the entire city, and supports dynamic updates, all with an application-oriented approach. The spatiotemporal data framework for smart cities imposes several requirements on the new fundamental surveying and mapping technology, including high precision, real-time updates, multi-source integration, standardization, strong security, and ease of access. These requirements involve ensuring the accuracy and quality of spatial data, supporting the rapidly changing urban environment, and enhancing data diversity and utility through the integration of various data sources such as remote sensing images and ground surveys. Moreover, the new fundamental surveying and mapping technology must adhere to international and national standards to ensure data interoperability and implement security measures to protect data and personal privacy. Open data interfaces should be provided to promote data sharing, and the latest technologies, such as drones and LiDAR, should be utilized to improve data collection efficiency. Environmental sustainability, cost-effectiveness, compliance with relevant laws and regulations, and public participation are also essential considerations for building an efficient, reliable, and future-oriented smart city data platform.

With the implementation of major strategic tasks, such as the construction of Digital China and new infrastructure, and the rapid development of next-generation information technologies, new fundamental surveying and mapping should shift from a cartographic mindset to an information mindset, driving comprehensive innovation in product models.[16–18] Several issues should be addressed urgently: (1) data that are formal but essentially paper maps, (2) abstract representations of the real world by individual elements, scales, and in a fragmented manner, (3) a single form of results that cannot meet diverse needs, and (4) the insufficient structuring and lack of rich semantic information, making spatial analysis and decision-making support challenging.

4. Application Case of New Fundamental Surveying and Mapping in the Spatiotemporal Data Framework of Smart Cities—A Case Study of Beijing's "One Map" of Smart City

4.1 Overall framework of Beijing's "One Map" of smart city construction

To solve the problem of moving from cartography to information service, Beijing's "One Map" of smart city is constructed on the basis of new fundamental surveying and mapping data with three-depersonalization (3D), materialization, and sanitization, including the following three parts: the processing and fusion of the city's new type of mapping data, the extraction of two-depersonalization (2D) and 3D information, and map design and compilation. As a customizable general base map, Beijing's "One Map" of smart city supports the daily operational needs of numerous municipal departments. The overall architecture and basic concept are illustrated in Fig. 1.

4.1.1 Data processing and fusion

Data processing and fusion are mainly based on new fundamental surveying and mapping data. This component addresses various data sources from different industries with different types and formats. These include foundational geospatial data, census survey data, planning and approval data, and government thematic data. By comparing and analyzing these data, the integration and governance rules and technical methods for different data sources are designed. According to the requirements of the "One Map" of smart city, a database structure system is established, creating an integrated electronic map foundational database within a unified spatial framework.

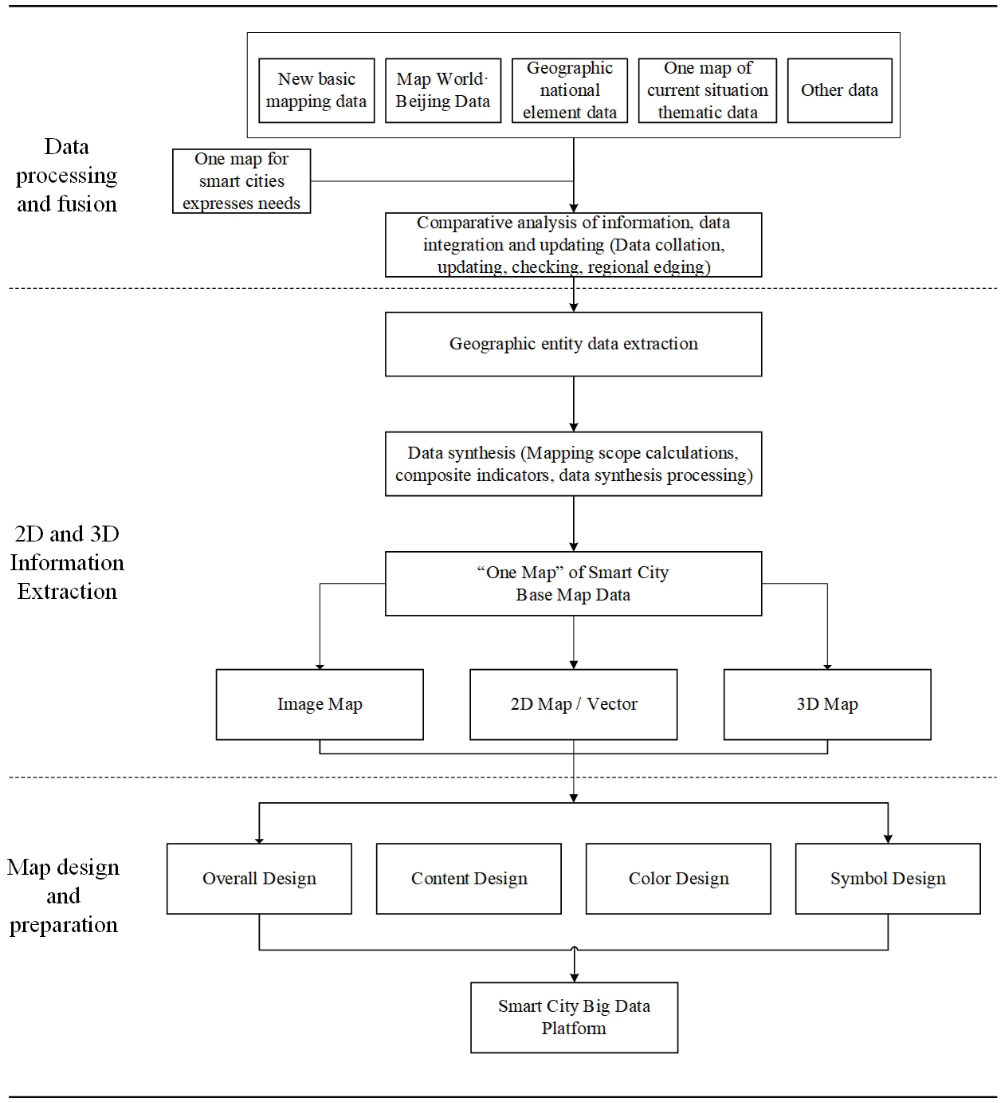

Fig. 1. Basic idea of generating a map of smart city based on new fundamental surveying and mapping.

4.1.2 2D and 3D information extraction

The 2D and 3D information for the "One Map" base map data is extracted and produced on demand on the basis of a new fundamental surveying and mapping collection, which includes several key elements, as follows. Remote Sensing Imagery: This includes a satellite Digital Orthophoto Map with a spatial resolution of 0.8 m and aerial orthophotos with spatial resolutions of 0.2 and 0.5 m. Vector Data: This includes over 40 layers of data in six major categories: residential areas, transportation, water systems, vegetation, boundaries, and administrative regions, points of interest (POI), and areas of interest. LiDAR Data: Using airborne LiDAR with a density of 16 points per square meter in plains and 8 points per square meter in mountainous areas, terrain data with 0.5- and 1-m grids are generated. These serve as the foundational 3D spatial data, from which terrain-level, city-level, and component-level data are extracted.

4.1.3 Map design and compilation

This component involves the overall content design, map visualization techniques, load balancing control, and platform design. The goal is to establish a rapid production process for government electronic maps, resulting in comprehensive and detailed maps for urban management. Key issues addressed include map visualization methods and effects, tile map publishing techniques, POI load balancing, and map information volume calculations, resulting in diverse multi-style, multi-scale maps.

Beijing's "One Map" of smart city effectively integrates new surveying and mapping data processing, 2D and 3D information extraction, and map design and compilation into a cohesive framework, supporting the smart city's infrastructure and service needs.

4.2 Key technologies for deriving the "One Map" of smart city from new fundamental surveying and mapping

4.2.1 Deriving seamless electronic maps based on geographic entities

Leveraging the results of new fundamental surveying and mapping in Beijing and the city's geographic entity seamless generalization and mapping system, we developed a knowledge base for automated topographic map generalization. This knowledge base incorporates multiple feature constraints, including semantics, geometry, topology, and spatial distribution. The key technologies for the seamless generalization and representation of geographic entities have been proposed, enabling the transformation of geographic entity data from fixed scales to seamless comprehensive representations. This approach addresses three critical challenges: geometric information compensation, entity data integration, and cartographic derivation and adaptation.

The process involves several steps: data preprocessing, comprehensive processing, cartographic derivation, and quality check. This system enables the automatic derivation of geographic entities into electronic maps, as illustrated in Fig. 2. By employing these technologies, the seamless generalization and comprehensive representation of geographic data are achieved, facilitating the creation of accurate, detailed, and adaptable electronic maps for smart city applications.

4.2.2 Multiscale automatic generalization algorithm for point features using multi-dimensional priority matrix

To address the automatic extraction of point features, specifically for place names and POI data, an automatic labeling based on the feature library was first implemented. A multi-dimensional priority matrix was designed according to the classification, labels, importance, and name characteristics of geographic entities. This matrix is used to evaluate the codes and labels

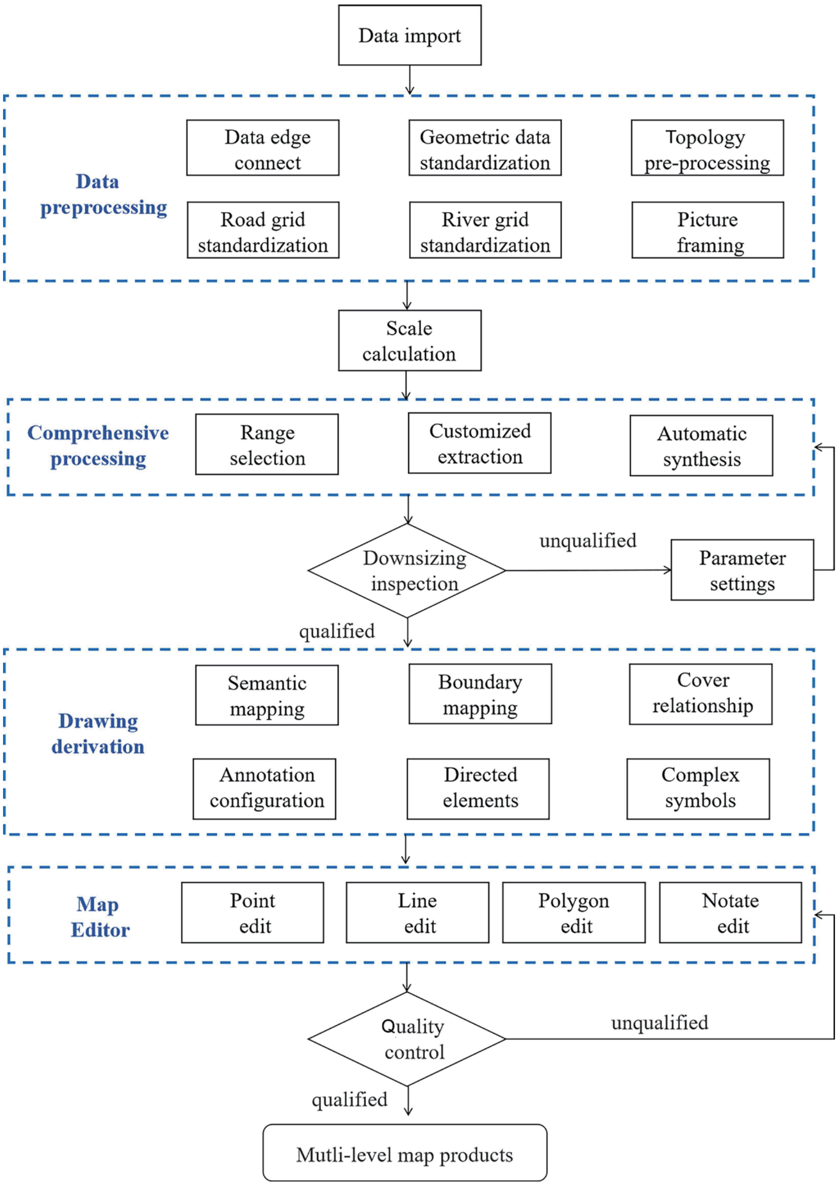

Fig. 2. (Color online) Overall technical route for deriving electronic maps from geographic entities through generalization.

of POIs by comparing each entry with the content in the priority library. When a complete match is found, the corresponding priority value is assigned to the POI. The proposed method includes a uniform grid-based thinning algorithm, a hierarchical selection control method under a graded system, and step-by-step extraction rules where only the highest priority feature is retained within each grid. This approach ensures precise extraction, logical consistency, and the load balancing of place names and POIs in multi-scale electronic maps (see Figs. 3 and 4).

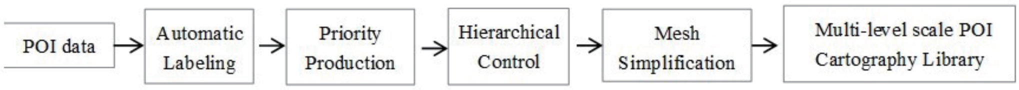

Fig. 3. Overall technical route for deriving electronic maps from POI data through generalization thinning of a homogeneous grid.

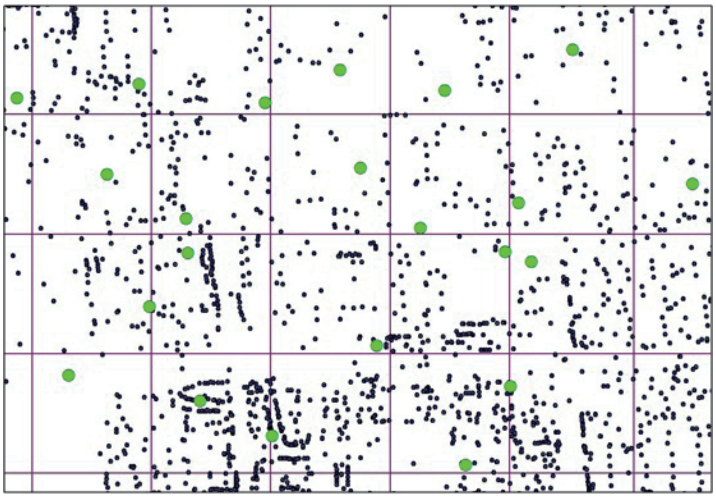

Fig. 4. (Color online) Thinning of a homogeneous grid for POI data.

4.2.3 Establishing a cartographic rules library and shared rules for different application scenarios

To address the challenge of expressing the same database in multiple scenarios, unified cartographic technical standards for same-source data across different application scenarios have been developed. A cartographic rules library has been established to meet the needs of various application scenarios. This library includes symbol libraries, color configuration libraries, graphic libraries, and cartographic expression rules for different types and levels of elements at various scales. It supports the release of multiple map service models, such as conventional, imagery, grayscale, and extreme night blue versions, forming an integrated cartographic process that satisfies Level of Detail display effects (Fig. 5).

4.2.4 Optimal map tile scheme for Beijing 2000 coordinate system and overcoming vector-raster overlay challenges

To meet the requirements of displaying the clearest resolution of 1:500 topographic maps within the Beijing 2000 coordinate system, a sequence of map tiles with a maximum scale of

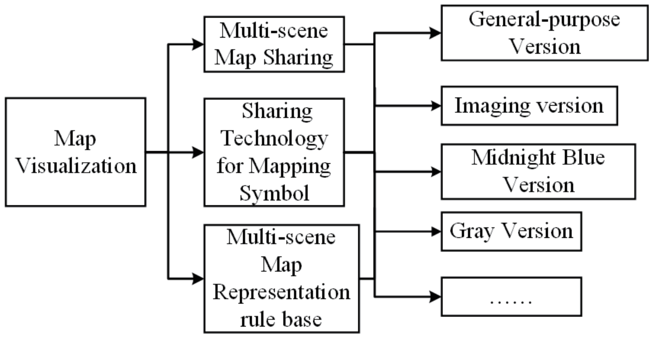

Fig. 5. Multi-scenario electronic map production.

1:378 has been proposed. This scheme calculates the position of each pixel of the original data in tiles at different resolutions and scales, achieving a consistent adaptation and clear display of 2D and 3D map data under the Beijing 2000 coordinate system. Compared with tiles of the same scale, this scheme occupies less storage space.

Furthermore, to address the positional offset issues between vector data, raster tiles, and vector tiles in the new fundamental surveying and mapping under the Beijing 2000 coordinate system, uniform rules for scale, origin positioning, and display resolution values were established for the production data and tile process in the operation software. A tool was developed to enable the compatible overlay display of raster and vector tiles across different software programs based on the Beijing 2000 coordinate system. This tool overcomes the differences in data and service platforms and software usage among various government departments, resolving issues related to the production of map data products and the cross-platform compatibility of map overlays.

4.3 Major achievements in the construction of Beijing's "One Map" of smart city

The construction of Beijing's "One Map" of smart city in this study is application-oriented, integrating various existing foundational geographic information, thematic information, planning approval information, and other multi-source data. This effort has yielded comprehensive 3D general map data for the entire city, resulting in a standardized, rich, and dynamic "One Map" for Beijing that integrates both 2D and 3D data, covers the entire city, and supports dynamic updates. A variety of styles and multi-scale electronic maps covering the entire city were created, including vector databases, electronic maps, accompanying map data, and tile data. Big data was successfully integrated and shared on the cloud and blockchain, constructing a "seven connections and one leveling" spatiotemporal digital base.

On the basis of content and hierarchical structure, real-world 3D models can be categorized into terrain level, city level, and component level. This includes city-wide terrain-level real-world 3D models, city-level real-world 3D models of the core and subcenter areas, and component-level real-world 3D models of the above-ground and underground, as well as indoor and outdoor areas of Lize Business District. The electronic map and the terrain-level, city-level, and component-level real-world 3D models are illustrated in Fig. 6.

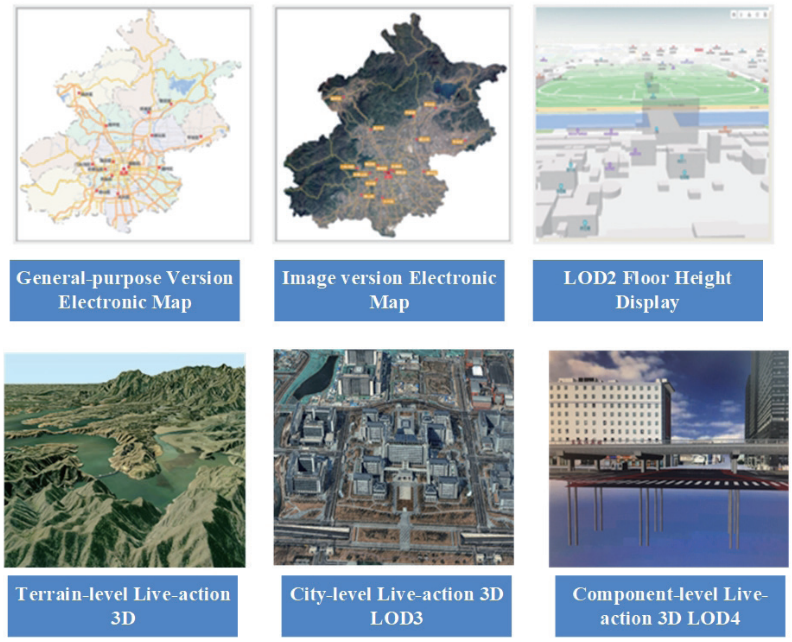

Fig. 6. (Color online) New fundamental surveying and mapping results in the "One Map" of smart city.

5. Conclusion

With the continuous development of information technology, new fundamental surveying and mapping results can establish a robust spatiotemporal digital foundation for smart city construction. This foundation facilitates the integration of multi-source data, enhances the standardization and sharing of urban data construction, and reduces construction costs. In this study, through the comprehensive application of new fundamental surveying and mapping geographic information data, we introduced the key technologies for building the spatiotemporal data foundation for the smart city construction of Beijing. In the future, it is recommended to strengthen the legal status of new fundamental surveying and mapping outcomes and the construction of smart spatiotemporal digital infrastructure in specialized planning and the integration of multiple plans (“multiple plans into one”). This includes enhancing inter-departmental coordination mechanisms, establishing operational dynamic implementation mechanisms, supporting digitized and multi-scenario smart city applications, improving the efficiency of smart city construction, and promoting the modernization of urban governance systems and capabilities.

References

1 W. Fan: Geomatics Spatial Inf. Technol. **45** (2022) 111 (in Chinese).
2 F. Pan: Geomatics Spatial Inf. Technol. **42** (2019) 237 (in Chinese).
3 J. Xiao, P. Li, and H. Li: Bull. Surv. Mapp. **01** (2022) 164 (in Chinese).
4 J. Han, X. Tu, and Y. Chen: Geomatics & Spatial Inf. Technol. **45** (2022) 37 (in Chinese).

5 M. Huang: Bull. Surv. Mapp. (2024) 46 (in Chinese).
6 H. Che: Geomatics & Spatial Inf. Technol. **47** (2024) 106 (in Chinese).
7 J. Yang, S. Deng, and P. Zhao: Technol. Innovation Appl. **12** (2022) 158 (in Chinese).
8 X. Li, X. Zhang, and C. Zhou: Geomatics Spatial Inf. Technol. **45** (2022) 15 (in Chinese).
9 H. Xu: China Surv. Mapp. **09** (2020) 8 (in Chinese).
10 M. Li, Z. Chen, and C. Zhou: China Land Sci. **34** (2020) 69 (in Chinese).
11 H. He, J. Zhang, and X. Guo: J. Beijing Univ. Civ. Eng. Archit. **35** (2019) 70 (in Chinese).
12 C. Li, J. Yin, and X. Liu: Sci. Surv. Mapp. **44** (2019) 230 (in Chinese).
13 J. Liu, C. Guo, and X. Fu: Inf. Technol. Network Secur. **38** (2019) 1 (in Chinese).
14 J. Zhang: West. Resour. **06** (2019) 156 (in Chinese).
15 Y. Jiang: Resour. Inf. Eng. **37** (2022) 115 (in Chinese).
16 Y. Zhao: Surv. World. **04** (2022) 86 (in Chinese).
17 L. Wang, G. Guo, and Y. Liu: Bull. Surv. Mapp. **02** (2022) 20 (in Chinese).
18 J. Liu, Y. Zhang, and J. Wu: Geomatics & Spatial Inf. Technol. **44** (2021) 114 (in Chinese).

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