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Application Research of Engineering Surveying and Digital Mapping Technology in Building Engineering Surveying

Jiahao Lu*

Hunan University of Information Technology, Department of Engineering Management, Changsha, Hunan, China

Abstract: Engineering surveying and digital mapping constitute fundamental technical underpinnings for international conference on environment engineering, urban planning and design. When existing studies mostly focus on the principle of individual digital surveying and mapping technologies and phased application reviews, yet few conduct empirical quantitative analysis based on local practical engineering data. Moreover, scarce research summarizes localized adaptation routes and practical optimization schemes for digital surveying and mapping from three differentiated construction scenarios: urban historic conservation, super high-rise cluster construction and intelligent operation & maintenance of large-scale building complexes. Taking practical construction projects in Changsha as research samples, this paper quantitatively calculates precision, construction period and cost optimization indicators of multi-source surveying technologies including 3D laser scanning, RTK, oblique photogrammetry and BIM-digital twin across various building scenarios. With measured data from three completed engineering projects in Changsha, the paper quantitatively verifies the economic benefits and error control effects of full-cycle digital surveying applications to supplement regional empirical data. In response to practical drawbacks of Changsha's historic blocks, landmark super high-rises and intelligent building complexes, this study develops combined technology selection schemes adaptable to the construction conditions of Hunan Province. Combined with the progress of smart city construction in Changsha, targeted improvement strategies are proposed for the digital transformation of the local surveying and mapping industry in Hunan.

1 Innovative Application of Digital Mapping Technology in Each Stage of Building Engineering Surveying

1.1 Planning and Design Stage of Building Engineering

In the planning and design stage of building engineering, the introduction of digital mapping technology provides a scientific basis for the optimization and decision-making of design schemes, improving design quality and efficiency[1] . Through technologies such as 3D laser scanning and oblique photogrammetry, designers can quickly obtain high-precision 3D data of the construction site and intuitively analyze elements such as topography, geomorphology, and surrounding environment[2]. Using the obtained real-scene 3D model, designers can deliberate on schemes, optimize building layout and appearance in a virtual environment, and improve the rationality and feasibility of design by means of digitalization. The application of Building Information Modeling (BIM) further promotes the digital collaboration process in the design stage[3]. By integrating design data of various disciplines on the model platform, seamless connection and sharing of design information are realized, reducing design errors and omissions, and improving design efficiency[4]. In addition, digital mapping technology also provides a new idea for the visual display of design schemes[5]. By combining the design model with the real-scene 3D model, realistic building visualization scenes can be produced, enabling the owner to experience the design scheme immersively and promoting the effective communication of design intentions[6].

1.2 Construction Stage of Building Engineering

With the rapid development of digital mapping technology, the construction of building engineering has ushered in a new era of intelligent and refined management. Real-time Kinematic (RTK) technology has brought a subversive change to construction lofting control with its real-time dynamic and high-precision characteristics. Using this technology, engineers can obtain the 3D coordinates of construction machinery in real time, accurately control its operation trajectory, and significantly improve construction efficiency and quality. Terrestrial 3D laser scanning technology can conduct all-round monitoring of building structure deformation. By periodically scanning the building and comparing and analyzing the point cloud data with the design model, construction deviations and potential structural safety

* Corresponding author: 305581025@qq.com

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hazards can be found in a timely manner. UAV low-altitude photogrammetry technology provides important technical support for project supervision. By regularly taking aerial photos of the construction site, high-definition orthophotos and 3D models are automatically generated, which intuitively present the project progress and construction status, providing strong support for scientific decision-making. In the final stage of construction, the indoor mobile measurement system can quickly obtain refined as-built survey data, helping the project pass the acceptance smoothly.

1.3 Operation and Maintenance Stage of Building Engineering

When the building engineering enters the operation and maintenance stage, digital mapping technology provides innovative support for intelligent operation and maintenance. Through the in-depth integration of 3D real-scene models and Internet of Things (IoT) technology, an integrated intelligent facility management system with visualization, intelligence, and integration is developed. Using this system, operation and maintenance personnel can real-time monitor the operation status of building facilities in a 3D visualization scene, and at the same time, by correlating and analyzing IoT sensor data, they can timely diagnose faults, optimize energy allocation, and realize intelligent and refined facility management. The comprehensive application of LiDAR and high-resolution satellite remote sensing technology provides a more comprehensive and long-term means for monitoring building settlement. By periodically conducting LiDAR scanning and satellite image collection in the building area, combined with high-precision data processing algorithms, the temporal and spatial distribution characteristics of building settlement can be accurately quantified, and potential safety risks can be found in advance. Airborne LiDAR technology provides a new technical dimension for the refined detection of engineering structures. Regularly using airborne LiDAR to obtain data on building elevation and volume changes can realize millimeter-level deformation monitoring, providing an intuitive and reliable basis for building health diagnosis.

2 Analysis of Typical Engineering Cases

2.1 Case 1: Digital Protection of Historical and Cultural Blocks

Digital mapping technology plays an important role in the digital protection of historical and cultural blocks. Faced with the problems of complex and diverse architectural styles and difficult acquisition of surveying and mapping data in the block, the handheld mobile measurement system, with its flexible and efficient characteristics, realizes the rapid acquisition of high-precision 3D real-scene data of the block and accurately constructs the physical 3D model of ancient buildings. Oblique photogrammetry technology combines oblique photogrammetry data with mobile measurement point clouds, and uses intelligent algorithms to optimize textures, realizing high-precision restoration of detailed architectural features and further enhancing the authenticity and visual expression of the digital model.

Taking the digital protection project of Chaozong Street and Taiping Street Historic Districts in Changsha as an example[7], the conventional manual surveying method using steel rulers and total stations is replaced by an integrated air-ground digital surveying and mapping technical system: (1) Five-lens oblique photogrammetry UAVs produced by DJI are adopted for full-area aerial survey to acquire overall real-scene image data of the blocks; (2) Handheld SLAM 3D laser scanners are deployed on the ground to access narrow alleys and indoor spaces of ancient buildings, eliminating data missing at building interiors and cornice blind zones inaccessible to UAVs; (3) Terrestrial fixed-station 3D LiDAR is supplemented for refined scanning of key heritage buildings including Wenchang Temple Annex Hall and Former Residence of Jiu Jin, achieving a point cloud sampling density of 5 mm per point for individual buildings.

Field application results demonstrate that the originally estimated 180-day period for full-block traditional manual survey is shortened to 42 days via digital surveying, raising working efficiency by 76.7%. Three-dimensional solid models, architectural CAD drawings of plan, elevation and section as well as digital archives of heritage buildings for the whole districts are completed, enabling millimeter-level reproduction of carved components and weathering traces on stone steles. All surveying outcomes are incorporated into the GIS database of Changsha historic buildings to support construction drawing design for the conservation renovation of Taiping Street and organic renewal of Chaozong Street. Meanwhile, an online 3D roaming platform is developed to facilitate digital revitalization of cultural tourism, and relevant data have been applied in the fourth general survey covering 120 historic buildings across Changsha.

This high-precision digital achievement significantly improves the efficiency of ancient building surveying and mapping, laying a solid foundation for the digital protection, research, and inheritance of historical and cultural heritage. Ancient buildings are accurately preserved and vividly reproduced with the support of digital technology, providing a carrier for the continuation of the city's historical context.

2.2 Case 2: Digital Construction of Super High-Rise Building Groups

It is difficult to set up a high-precision surveying control network for super high-rise building groups, and the requirements for construction progress and quality control are extremely high. Any slight deviation may lead to major engineering risks. During the construction process, airborne LiDAR is used to quickly obtain high-precision 3D coordinates of the building group area, which is integrated with terrestrial static 3D laser scanning data, significantly simplifying the establishment process of the elevation control network, overcoming the difficulty of surveying and mapping network layout, and reducing construction risks. Regular high-altitude monitoring of the building group using oblique photogrammetry technology provides strong guarantee for construction safety and progress control. For instance, digital surveying and mapping technologies are implemented throughout the entire construction cycle in the survey project of the Changsha International Finance Square (Changsha IFS) super high-rise cluster[8].

(1) Planning and foundation construction phase: The Beidou dual-frequency RTK technology is employed for static layout of the primary overall horizontal control network. Airborne LiDAR is used to collect original topographic point cloud data, which is fused with terrestrial 3D laser scanning data to establish the foundational site BIM model. The benchmark network for foundation pit slope deformation monitoring is completed in a single procedure. Compared with conventional traverse surveying, the construction period for control point arrangement is cut by 40%, with horizontal positioning error controlled within ±1.5 mm.

(2) Main steel structure construction phase: RTK dynamic setting-out combined with periodic terrestrial 3D laser scanning is adopted on construction floors. Full-tower point cloud inspection is implemented every three floors and automatically matched with the steel-structure BIM model to rectify installation deviations of steel columns promptly. Accordingly, the rework rate of steel assembly declines from the industrial average of 8% to 1.2%.

(3) Construction supervision: The general contractor carries out weekly oblique photogrammetry with UAVs across the construction site to produce orthophotos and real-scene models, which are compared with the 4D-BIM schedule for visualized progress control of super high-rise construction milestones.

Quantified economic benefits are summarized as follows: Digital surveying saves approximately 3.2 million RMB in steel material losses induced by survey rework, and the main structure topping-out is finished 12 days ahead of schedule. In addition, scanning data are applied to establish digital archives of the Song-dynasty block ruins on the project site, realizing coordinated implementation of super high-rise construction and digital preservation of ancient relics.

The comprehensive application of these cutting-edge surveying and mapping technologies not only meets the strict requirements of the construction of super high-rise building groups but also provides key technical support for their construction, significantly improving the modernization level of engineering construction.

2.3 Case 3: Digital Operation and Maintenance of Large-Scale Building Complexes

Large-scale building complexes have a variety of facilities and equipment, and the problem of information islands among various professions is serious, so an intelligent comprehensive management scheme is urgently needed. Through comprehensive data collection using technologies such as oblique photogrammetry, airborne/vehicle-borne LiDAR, and indoor mobile measurement, an integrated management platform combining BIM, Geographic Information System (GIS), and IoT can be built. In this platform, the geometric and attribute information of various facilities and equipment are seamlessly connected, and operation data can be transmitted and shared in real time. Managers can real-time monitor and manage the operation status of the building complex through an integrated interface in a virtual scene. With the support of digital twin technology, the issuance of scheduling instructions, the diagnosis of equipment faults, and the formulation of emergency plans have all achieved a higher degree of intelligence.

Taking the full-life-cycle digital operation and maintenance project of Hunan Creative Design Headquarters Building complex as an example[9], the technical implementation route is specified as follows:

(1) As-built survey stage: Three surveying approaches are integrated. Vehicle-borne LiDAR and oblique photogrammetry are utilized outdoors to collect three-dimensional data of building facades and municipal pipelines within the compound, while mobile SLAM survey systems conduct floor-by-floor scanning for indoor spaces and pipeline coordinates to form a complete as-built point cloud dataset.

(2) Data integration: The measured point cloud data are used to reversely revise the construction BIM model. Data interfaces among BIM, GIS and the Internet of Things (IoT) are interconnected to develop an exclusive digital twin operation and maintenance platform for the project.

(3) Practical operation and maintenance: Real-time monitoring data from power distribution, water supply and drainage, central air-conditioning and fire-fighting sensors are imported into the 3D realistic model. On the visualized platform, maintenance staff can realize automatic early warning of equipment faults, intelligent energy consumption analysis and rapid location of underground pipeline defects.

Application results indicate that after the adoption of the intelligent operation and maintenance platform, the annual labor cost for regular equipment inspection is reduced by 38%, and the energy consumption of central air conditioning drops by 16.3% via big data optimization. Meanwhile, the troubleshooting duration for underground pipeline leakage is shortened from the conventional 2–3 days to less than 2 hours.

This whole-life cycle intelligent management scheme promotes the refinement of the operation and maintenance work of large-scale building complexes and provides motivation for urban renewal by means of digitalization, promoting the development and upgrading of urban complexes in the intelligent era.

3 Effective Suggestions for Promoting the Digital Transformation of the Building Surveying Industry

3.1 Improve the Digital Literacy of Practitioners and Promote Education and Training on Digital Mapping Technology

The core of the digital transformation of the building surveying industry lies in talent support. At present, there is still a certain lag in the talent training system in the industry. Many practitioners lack systematic understanding of new technologies and concepts and find it difficult to adapt to the needs of digital transformation. Therefore, it is necessary to vigorously promote education and training on digital mapping technology and build a comprehensive and multi-level talent training system. First of all, digital mapping technology can be incorporated into the core courses of surveying and mapping majors in colleges and universities, optimize teaching content, innovate teaching models, and cultivate compound talents. Secondly, it is necessary to carry out diversified continuing education projects for practitioners, popularize the concept of digital mapping technology, and impart practical skills through a combination of online and offline methods to improve their comprehensive quality. At the same time, enterprises should be encouraged to cooperate with colleges and universities to establish industry-university integration talent training bases, sharpen skills in practice, and continuously transport high-quality talents for the industry to provide strong support for digital transformation.

3.2 Improve the Data Standard and Specification System and Promote the Interconnection of Building Surveying and Mapping Data

The interconnection of building surveying and mapping data is an important cornerstone for realizing digital transformation. At present, China's building surveying and mapping data standard and specification system is not yet perfect. Various data lack unified standards in the links of collection, processing, exchange, and application, leading to prominent problems of data islands. Therefore, it is necessary to improve the data standard and specification system and promote the standardized and standardized management of data. First of all, it is necessary to accelerate the formulation of standard specifications for each link of building surveying and mapping data from collection to application, providing a basis for the standardized management of data. Secondly, it is necessary to establish a sound data quality control and evaluation mechanism, strengthen the whole-process management of data production, and improve data quality. Finally, a data sharing platform should be built to promote the interconnection of data between different systems, departments, and regions, and improve data utilization rate. At the same time, it is necessary to strengthen data security protection, improve the data property right management system, and safeguard the rights and interests of data subjects.

3.3 Develop Intelligent Data Analysis and Mining Tools and Expand the Application Depth of Digital Achievements

Massive surveying and mapping data contains rich spatial information and application value. However, at present, many digital surveying and mapping achievements are still at the level of visual display, and the in-depth application of data is insufficient, failing to give full play to their value. Therefore, developing intelligent data analysis and mining tools can fully release data value and improve data availability and application efficiency. First of all, it is necessary to make full use of cutting-edge technologies such as big data and artificial intelligence to develop intelligent data processing and information extraction tools, realize automatic analysis of massive surveying and mapping data, reduce the burden of manual processing, and improve data processing efficiency. Secondly, it is necessary to innovate data application models and develop data analysis and mining tools oriented to industry needs. For example, develop building structure safety assessment tools to intelligently analyze multi-temporal point cloud data and timely warn of structural risks; develop building energy consumption analysis tools to conduct integrated mining of BIM data and IoT data to fully optimize energy management schemes.

3.4 Strengthen Industry-University-Research-Application Cooperation and Accelerate the Transformation of Scientific and Technological Achievements into Productivity

Scientific and technological progress is an important driving force for the digital transformation of the building surveying industry. At present, China has made a series of scientific research achievements in the field of digital mapping, but there is still a certain lag in their transformation and application, which is difficult to effectively support the development needs of the industry. Therefore, it is necessary to strengthen industry-university-research-application cooperation and build an efficient and collaborative mechanism for the transformation of scientific and technological achievements. For example, build an industry-university-research-application cooperation platform to promote exchanges and cooperation between colleges and universities, scientific research institutes, and enterprises, and accelerate the application verification and iterative optimization of scientific research achievements. It is also necessary to improve the mechanism for the transformation of scientific and technological achievements, establish a sound performance evaluation system for achievement transformation, and take the transformation of achievements as an important basis for the title evaluation of scientific researchers and project approval. At the same time, it is necessary to increase financial support for the transformation of scientific and technological achievements and expand the financing channels for the transformation of scientific and technological achievements.

3.5 Adapt to Cutting-Edge Concepts such as Digital Twin, Metaverse and Low-Altitude Economy, and Explore New Blue Oceans of Digital Mapping

Engineering surveying and digital mapping technologies are important technical supports for building the building digital twin system and are widely used in this field. To this end, we should keep up with the pace of cutting-edge technological development, actively embrace the concept of digital twin, and accelerate the construction of a digital twin system for the whole life cycle of buildings. Using technologies such as oblique photogrammetry and LiDAR to obtain high-precision and multi-dimensional building data, and then realizing data fusion through platforms such as BIM and GIS, a building digital twin model integrating geometric, physical, functional, and other multi-dimensional information is constructed to realize digital management of the whole process from design, construction to operation and maintenance. The surveying and mapping industry also needs to take the initiative to integrate into the metaverse industrial ecology and use high-precision surveying and mapping data to build a highly realistic, multi-sensory, and interactive building virtual space, providing rich spatial scenes for the metaverse. At the same time, it is necessary to strengthen the integrated innovation with 5G communication technology, artificial intelligence, blockchain, and other technologies to expand the application boundary of digital mapping.

Referring to the practical experience of the Wenchang Pavilion digital-human metaverse roaming project[10], real-scene surveying data of historic blocks in Changsha are adopted to develop metaverse scenarios for ancient architectures. Supported by Changsha's pilot policies for low-altitude economy, large-scale applications of UAV aerial survey are further promoted in planning mapping of new urban districts and surveying for old residential community renovation across Changsha.

3.6 Actively Explore the Innovative Application of Engineering Surveying and Digital Mapping Technology in Smart City Construction

With the continuous advancement of new smart city construction, digital mapping technology has ushered in greater application space in fields such as urban refined management and intelligent services. As the spatial information infrastructure of smart cities, digital mapping technology can provide solid support for cities to realize full-element, full-cycle, and full-space digital management. By comprehensively using multi-source data collection methods such as satellite remote sensing, LiDAR, and mobile measurement, a high-precision 3D spatial data system covering the whole city can be built. Combined with IoT, big data, and other technologies, real-time perception and analysis of urban operation can be realized, providing digital support for urban management decisions. For example, using oblique photogrammetry and mobile measurement data, a city 3D visualization management platform can be established to intuitively present the urban spatial layout and assist in urban pattern optimization and renewal and transformation; by analyzing the obtained high-precision topographic data, potential urban waterlogging risks can be accurately identified to guide sponge city construction; using indoor and outdoor integrated 3D models, refined management of key places such as underground pipe networks can be realized to improve urban safety.

4 Conclusion

Based on empirical data from three practical construction projects in Changsha, this paper elaborates on the application value of integrated multi-technology in various building engineering scenarios. The application of digital mapping technology in building engineering surveying has improved surveying efficiency and accuracy, providing digital support for the whole-life cycle management of buildings. In the future, under the guidance of emerging concepts such as digital twin and City Information Modeling (CIM), digital mapping technology will further expand its application potential, providing key support for smart city and digital construction. In addition, promoting the digital transformation of the building surveying industry also requires coordinated development in many aspects such as data standards, talent training, and industry-university-research-application. Accelerating the innovative breakthrough and integrated application of engineering surveying and digital mapping technologies can continuously explore new blue oceans of digital mapping and promote the high-quality development of the building surveying industry.

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