Applied Science and Innovative Research
ISSN 2474-4972 (Print) ISSN 2474-4980 (Online)
Vol. 8, No. 3, 2024
www.scholink.org/ojs/index.php/asir

Original Paper

Analysis of the Application Progress of BIM+GIS in Bridge Engineering

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Received: July 8, 2024 Accepted: August 6, 2024 Online Published: August 16, 2024
doi:10.22158/asir.v8n3p163 URL: http://doi.org/10.22158/asir.v8n3p163

Abstract

In recent years, the combined application of BIM and GIS technologies has demonstrated significant advantages in rail transit construction. As a crucial component, bridges are characterized by high complexity and diversity, thereby necessitating higher demands and standards for the integration of BIM and GIS technologies. Currently, some scholars both domestically and internationally have explored the application value and methods of BIM+GIS technologies at various stages of bridge engineering. This paper provides a comprehensive review of the application of BIM+GIS technologies throughout the entire lifecycle of bridge engineering (including design, construction, management, etc.), while also analyzing the advantages and existing challenges of BIM+GIS technologies in bridge construction.

Keywords

BIM, GIS, Bridge Engineering, Application Progress

1. Introduction

Building Information Modeling (BIM) is a technology that creates a three-dimensional model of a building using digital techniques. This model includes geometric information, status information, and specialized attributes of building components, as well as the status information of non-component objects, such as space and motion behavior. It provides a detailed and intuitive representation of the geometric, physical, and additional attributes, as well as the manufacturing processes involved in bridge engineering. BIM is widely used in the fields of architectural design, construction, and management (Lu et al., 2021). Geographic Information Systems (GIS) are technological systems for collecting, storing, computing, managing, analyzing, and displaying geographic information, encompassing both geometric and attribute information of spatial elements. GIS is extensively applied in urban planning (Lu et al., 2021). Although the principles of these two technologies are similar, they differ significantly in application. For instance, BIM is primarily used for modeling structural information inside buildings, while GIS is mainly used for integrating spatial geographic information (Bai et al., 2017). BIM focuses more on indoor, small-scale, micro-level data, whereas GIS is concerned with outdoor, large-scale, macro-level data (El et al., 2013; Liu et al., 2017). Therefore, while both technologies are powerful within their respective fields, each has its own advantages and limitations. Integrating BIM and GIS can complement their strengths, break down data silos, and promote data fusion, enabling their application throughout the entire lifecycle of construction projects. This integration has been widely demonstrated in various fields such as urban planning and rail transit construction.

The design, construction, and management of bridge engineering are highly complex and diverse. With the development of urban construction, there has been a significant increase in the demand for digitization, intelligence, scientific rigor, and visualization in bridge engineering (Liu, 2022). Traditional methods, relying on static two-dimensional information such as drawings, text, and tables, as well as the inefficient manual collection of bridge status information, can no longer meet the needs of modern bridge construction in China.

Some scholars have already applied BIM+GIS technologies to various stages of bridge construction, achieving promising results (Hou et al., 2020; Jin, 2022; Wang, 2020; Wei, 2021; Zhang, 2021). This paper aims to summarize the application methods and current practices of BIM+GIS technologies in bridge engineering based on existing case studies and to analyze the advantages and challenges associated with their application.

2. Bridge Engineering Design

In bridge design, it is essential to consider fundamental factors such as bridge function, scale, structure, materials, and the complexity of construction. At the same time, environmental factors must be fully taken into account, ensuring that the design is adapted to the surrounding environment. Therefore, high-quality bridge engineering design requires the organic integration of engineering information with environmental information (Zhao, 2014). BIM and GIS are powerful in their respective domains—BIM in three-dimensional building information modeling and GIS in geographic spatial information processing and visualization. The integration of these two technologies complements their strengths, allowing for the seamless embedding of engineering information into the environment, which proves to be highly effective in bridge engineering design (Zhang, 2019).

Wang explored the application value of BIM+GIS technology in the preliminary design of bridges (Wang, 2020). In their study, they selected a planned bridge located in the heart of the Three Gorges Reservoir area, characterized by a sensitive environment and complex survey conditions. They first employed UAV (Unmanned Aerial Vehicle) oblique photography to capture real-world features from five angles (one vertical and four oblique) with synchronized exposure. The data obtained was then used to create a realistic 3D model with ContextCapture, serving as the design environment for BIM. Next, they used SuperMap iDesktop 9D and SuperMap iServer 9D to construct and publish a 3D service, followed by the development of a digital twin system using SuperMap iClient3D 9D for WebGL. Finally, they built a digital twin system for the design phase based on BIM+GIS through the SuperMap GIS 9D platform. This digital twin system enabled a direct, efficient, and streamlined process for comparing preliminary bridge design schemes and managing field surveys along the bridge's alignment (Wang, 2020).

Zhang also used UAV oblique photography and developed a BIM+GIS-based visual bridge design system using the OpenSceneGraph (OSG) 3D rendering engine (Zhang, 2021). Their research demonstrated that, through coordinate and model transformation, BIM design results could be displayed in real time within a GIS environment. This seamless integration of BIM and GIS enabled the visualization and automation of bridge design schemes. Their article provides a detailed presentation of data and model transformation between BIM and GIS. They tested their approach on a steel truss cable-stayed bridge in a newly constructed high-speed railway, showing significant results and outstanding efficiency (Wang, 2020).

3. Bridge Engineering Construction

The construction process of bridge engineering is complex and diverse, characterized by long durations, significant investment, and complicated management. Effective information management of the bridge construction process is crucial to improving project management efficiency and quality (Hu et al., 2010). Traditional bridge construction management often relies on dispersed and static information, which hinders the effective integration of critical data during the construction process and makes it difficult to provide timely feedback on encountered issues. Additionally, with numerous stakeholders involved in bridge construction, inadequate and delayed communication and information sharing can severely impact the project. By integrating BIM and GIS, the construction process can be digitally managed, enabling visual and dynamic control. This approach facilitates real-time monitoring, effective communication, and data integration, improving overall project management and efficiency.

Jia converted BIM models into GIS spatial data and used SQL Server to manage attribute data, establishing a hybrid database. They applied Earned Value Analysis (EVA) to control construction progress and utilized BIM+GIS for visualizing the construction schedule. They also performed secondary development of the GIS platform to achieve dynamic management of the bridge construction process, including quality, progress, cost, and reporting. Their case study on the G107 Handan to Maotou South Section reconstruction project demonstrated the platform's effectiveness and practicality, showing that it can perform deviation analysis and automatic warnings for construction progress (Jia, 2019). Similarly, Qin and colleagues developed a 3D digital management platform based on BIM+GIS for bridge construction progress, quality, and cost, achieving a transition from 3D-BIM to 5D-BIM. Their research detailed the system architecture of the platform, including the data layer (the base layer), service layer, and application layer (3D analysis, information, progress, quality, and cost management). This provides valuable insights for designing frameworks for BIM+GIS-based bridge construction management systems (Qin et al., 2017). The application value of BIM+GIS technology in bridge construction has also been confirmed in numerous other studies, demonstrating detailed itemization, powerful management and analysis functions, and the capability for real-time viewing and processing on mobile devices (Hou et al., 2020).

4. Bridge Engineering Monitoring and Management

China has a vast number of bridges, accounting for 47% of the world's new bridges. By the end of 2019, there were 878,300 highway bridges in China, totaling 60,634,600 meters. Among these, there were 5,716 major bridges with 10,332,300 meters and 108,344 large bridges with 29,237,500 meters. Additionally, the proportion of dangerous bridges was relatively high at 7.8% (Huang et al., 2022). With the large number of bridges in use, the increasing age of existing bridges, and the continuous growth in load and traffic, there is immense pressure on bridge condition monitoring and management. Traditional monitoring and management methods require substantial human and material resources, are costly, and often have measurement blind spots. There is an urgent need to establish intelligent, refined, visual, and clustered bridge monitoring and management systems.

Several scholars have explored and validated the application value of BIM+GIS technology in bridge health monitoring and management (Ding et al., 2022; Huang et al., 2022; Zhai, 2021; Wang, 2020). This paper focuses on the core principles and processes of building a bridge monitoring and management system based on BIM+GIS, with Wang Jijun' research as an example (Wang, 2020). A bridge monitoring and management system is a multidisciplinary, large-scale, and highly complex system. To achieve real-time monitoring, sensors need to be installed on key bridge components. The selection of sensors should focus on stability, advanced technology, interchangeability, and applicability. Specific types of sensors include those for wind speed and direction, temperature and humidity, deflection, and stress monitoring. The monitoring content primarily involves environmental and load conditions, overall structural response, and local structural response. Measurement points should cover common damage locations and span the entire bridge. Data collection and transmission should ensure the precision and completeness of raw data and sufficient storage capacity in the database. The system should preprocess and intelligently display the collected data and provide automatic warnings for situations exceeding safety standards. The construction process of a BIM+GIS bridge monitoring management platform mainly includes: 3D bridge BIM model construction: creating a detailed three-dimensional model of the bridge, GIS data acquisition: collecting relevant geographic and spatial data, BIM+GIS integration: converting and integrating data from BIM and GIS systems, rendering: enhancing the system's capability to load, process, and display data and functional platform design:

designing a user-friendly and comprehensive functional platform, focusing on human-computer interaction. In Wang's study, the functional modules included system homepage, project management, early warning center, information management, expert evaluation, and system management. The platform can also be personalized based on user or research needs.

5. Advantages and Challenges of BIM+GIS Technology in Bridge Engineering

Based on existing literature and research, the author believes that the main advantages of BIM+GIS technologies in bridge engineering lie in their ability to visualize, intelligently manage, and scientifically control the entire lifecycle of a bridge project. During the design phase, BIM+GIS technologies facilitate a more efficient and practical design by integrating the bridge with its environment. In the construction phase, these technologies enable real-time updates and effective information sharing, significantly enhancing the efficiency and quality of bridge construction. Additionally, utilizing BIM+GIS to establish an intelligent monitoring and management system allows for automatic detection, early warning, and efficient management and maintenance of bridge health. However, the application of BIM+GIS in bridge engineering still faces some unresolved issues and challenges. For instance, there is a lack of universal platforms that effectively combine both technologies; current software platform integrations can only achieve partial functionality, with significant limitations in analytical capabilities. Additionally, the integration of these two technologies under existing data standards remains challenging, making seamless, lossless, and reversible integration difficult. Most existing research is theoretical or based on individual bridge cases, lacking large-scale practical operations and applications.

6. Summary

This paper primarily discusses the application and value of BIM+GIS technologies throughout the entire lifecycle of bridge engineering, including design, construction, and inspection management. The integration of BIM+GIS technologies has enabled the digitalization, visualization, intelligence, and scientific development of bridge construction, demonstrating broad application prospects and significant value. However, due to some existing issues, there are currently few related case studies. Future efforts need to focus on expanding the application of BIM+GIS technologies in bridge engineering through more practical exploration and implementation.

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