

The Application of BIM Technology in Achieving a Balance between Greenness and Efficiency in H-Speed Rail Construction

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Abstract. This research is centered on BIM technology. By analyzing the technical gaps of typical cases such as the Anjiu Railway project, and drawing on the experience of prefabricated buildings and water conservancy projects, three integrated technology systems have been constructed: BIM + GIS + IoT / NB-IoT is used for long-distance environmental monitoring; BIM + intelligent bridge erection machine + RFID + InSAR is used for bridge settlement control; BIM + intelligent TBM + TSP is used for safe tunnel excavation. The research shows that the integrated technology system can break through information barriers and achieve real-time environmental monitoring and dynamic optimization of construction, ensuring efficiency while reducing ecological disturbance. Regarding the limitations of standardization and cost in technology promotion, in the future, green efficiency evaluation indicators should be constructed and the application of technology modules should be promoted, providing theoretical and practical support for green construction of high-speed railways.

Keywords: BIM; high-speed railway; integrated technology system; green construction; environmental monitoring.

1. Introduction

Against the backdrop of China's carbon peaking and neutrality goals and ecological civilization construction, high-speed railway (HSR) construction urgently needs to shift from extensive to green and efficient management. HSR projects have linear sites, complex geology, and ecological sensitivity. In order to achieve high-quality development of the HSR construction, it is essential to reduce embodied carbon emissions throughout the infrastructure life cycle including construction, maintenance, and renovation through a combination of structural optimization, prefabrication, material reuse, and intelligent maintenance [1]. Furthermore, improving construction efficiency to achieve a balance between greenness and efficiency is also the core requirement for high-quality HSR construction. Some scholars point out that overemphasizing environmental protection may extend schedules and increase costs [2]. On the other hand, blindly pursuing efficiency could result in soil erosion and ecological damage. This predicament impedes the high-quality and sustainable development of HSR.

Some suggest that most projects only apply a single technology. Even when Building Information Modeling (BIM) is adopted, it still remains difficult to balance greenness and efficiency [3]. In addition, the value of technologies is not fully used, and this leads to a situation where greenness and efficiency cannot be achieved at the same time. So, it is essential to build systematic and integrated technical systems to solve this problem.

This research focuses on green and efficient HSR construction and uses literature review methods. The technical gaps in the digital engineering of the Anjiu Railway Project are analyzed, and technology systems are drawn from other construction cases. These systems assess the feasibility in HSR construction and their contribution to improving the green-efficiency balance. Integrated systems including BIM, Geographic Information System (GIS), Internet of Things (IoT), Radio Frequency Identification (RFID), Interferometric Synthetic Aperture Radar (InSAR), and other technologies are developed. The research aims to fill the technical gaps in achieving the green-efficiency balance in HSR construction. The research provides both theoretical value and practical guidance for the high-quality and sustainable development of HSR.

2. Analysis of transferable technology combination

2.1. Analysis of the BIM + GIS + IoT technology system

The Anjiu High-Speed Railway project used a BIM+GIS+IoT digital construction platform. The platform integrates whole progress of the construction and effectively breaking information barriers between multiple processes. It significantly improved overall collaboration efficiency and control level [4]. The deep integration of technologies enables real-time and 3D monitoring of engineering information. This enhances resource allocation efficiency and risk identification and warning capabilities during construction [5,6]. However, the current monitoring system focuses mainly on people and machinery allocation while ecological indicators are weakly monitored. There is a lack of continuous tracking and assessment mechanisms for the surrounding ecosystem, and this poses potential risks of adverse effects on the regional ecological environment.

2.2. Analysis of the BIM + RFID + PDCA technology system

An R Commodity + Resettlement Housing Integrated TOD (R-TOD) prefabricated construction project innovatively constructed a prefabricated building information model based on BIM, integrating key elements of the entire life cycle of components, such as design, production, transportation, and installation, into a unified and traceable data foundation. On this basis, RFID radio frequency identification technology was introduced to implant unique identification codes for each component, enabling precise tracking and traceability management throughout the process from prefabrication to on-site installation, ensuring the accurate transmission of component information and seamless connection of each link. At the same time, the project established a Plan-Do-Check-Act (PDCA) cycle control mechanism, relying on real-time data collection and closed-loop optimization processes, to conduct dynamic monitoring, analysis, and continuous improvement of component production, transportation, and installation links, achieving active control and refined adjustment of the construction process [7]. Through the organic integration of the above-mentioned technologies and management methods, the level of component's refined management has been significantly enhanced, effectively avoiding rework caused by information errors and incorrect use of components. While ensuring the quality of the project, the construction efficiency has been greatly improved.

2.3. Analysis of BIM + TBM technology system

The Guangdong Water Resources Allocation Project in the Northern Bay of the South China Sea is a major national water conservancy project with a large construction scale and complex geological conditions. It has extremely high requirements for construction technology and management level. During the construction of this project, the team innovatively applied two key technologies, BIM and Tunnel Boring Machine (TBM). This forms a mode that integrates digitalization and mechanization. To address the tunnel excavation challenges under complex geological conditions, the project invested multiple TBM equipments and formulated a special construction management guideline to establish a control system [8]. The collaboration with the BIM platform provided a strong support for efficient excavation in hard rock area and ensuring the safety and quality of tunnel construction. The application of two key technologies significantly enhanced the intelligence level and management efficiency of tunnel construction under complex geological conditions. It provides solid technical support for the high-quality construction of this national water project.

3. A technical application system for achieving a balance between greenness and efficiency in high-speed rail construction based on BIM

3.1. BIM + GIS + IoT/NB-IoT technology system

Although IoT technology was used in the Anjiu High-Speed Railway project to summarize and track the key information during construction, no detection and protection of the water and soil

conditions of the construction environment were carried out. Narrow Band Internet of Things (NB-IoT), as an IoT communication technology that can cover long distances and large areas, can be effectively applied to the intelligent remote monitoring and early warning of long-distance linear engineering such as high-speed railway construction [9]. In addition, NB-IoT is often used in combination with ordinary IoT technology. This multiple structure integrates the flexible networking of ordinary IoT and the wide-area reliable transmission of NB-IoT and this improves the whole system efficiency. This technology system could be applied to long-distance linear engineering areas such as the HSR construction project and ecologically sensitive areas.

3.2. BIM + intelligent bridge lifting machine + RFID traceability + InSAR technology system

The technologies from the R-TOD project could be applied to HSR bridge construction. Developing a BIM model for prefabricated bridge components enables full-cycle information integration and material traceability using RFID. A digital twin platform then maps real-time data from the intelligent bridge erector onto the BIM model. This approach precisely guides construction while improving accuracy and reducing component waste and adjustments. Furthermore, introduce InSAR technology that is based on synthetic aperture radar phase information and multi-temporal analysis and enables millimeter-level settlement monitoring [10,11]. This technology could be applied to bridges and other artificial structures along the entire line. It is not possible to observe tunnels directly. Surface subsidence monitoring above tunnels could provide indirect assessment of potential risks. Satellite images are regularly acquired to generate deformation field maps. These maps are then overlaid with the BIM model to accurately identify excessive settlement areas. This provides data support for engineering reinforcement and environmental restoration and quantitatively assesses the impact of construction and operation on the surrounding environment. This technology system is applicable to prefabrication and erection of high-speed railway bridges. It is also applicable to large-scale deformation monitoring of subgrades as well as bridges and tunnels.

3.3. BIM + intelligent TBM + TSP geotechnical prediction technology system

Tunnel Seismic Prediction (TSP) is a seismic wave reflection method that could detect geological conditions ahead of tunnel excavation and effectively identifies faults and fractured zones which could provide early warnings and reduce safety risks [12]. Adopted from the Guangdong Water Resources Allocation Project for high-speed railway tunnels, TSP is integrated into a complete technical system. Before the construction it performs long-distance detection to accurately identify adverse geological risks such as faults and fracture zones. The BIM platform dynamically integrates geological prediction data along with TBM excavation parameters and tunnel design models. This constructs a visual digital twin which guides real-time adjustments of TBM posture and support schemes. This combination enables advanced knowledge of ahead geology and real-time TBM adjustment. It significantly improves construction efficiency and safety in complex geological conditions. It is applicable to high-speed railway tunnels and complex sections, as well as other tunnel projects requiring advanced geological prediction and intelligent excavation.

3.4. Technical limitations

3.4.1. Difficulties in promoting the technical framework

The integration of BIM, GIS and IoT involves the collection and interaction of multi-source heterogeneous data. Currently, there are no unified data interfaces and communication protocols among various technical systems, and multiple format conversions and coordinate registration are required during integration, which increases the difficulty of development and operation. Moreover, the application of these technologies is greatly affected by the construction environment. In projects such as the Anjiu Railway, the line passes through mountainous and water areas, and aerial photography is prone to creating model holes. The deployment of sensors is limited by signal coverage, resulting in insufficient continuity of monitoring data in complex geological scenarios.

Therefore, the full promotion of these technologies in projects with low standardization and complex geological conditions still face challenges.

3.4.2. High application costs make it difficult for small and medium-sized projects to fully adopt this solution

The implementation of the integrated technology system requires a significant investment in both software and hardware resources: high-performance modeling workstations, unmanned aerial surveying equipment, various IoT sensors, cloud platform storage and computing resources, as well as the labor costs of professional technicians. Taking the Anjiu Railway project as an example, the project invested in DJI Inspire 4 RTK drones, multiple types of slope and bridge monitoring sensors, and AI video surveillance systems, etc. The initial procurement and deployment costs were relatively high. For small and medium-sized construction projects, the introduction of the complete technical framework is difficult to achieve a balance between investment and output, which limits its application and promotion in a wider range of scenarios.

4. Conclusion

This article focuses on the difficulty of achieving efficiency and green synergy in high-speed rail construction and systematically presents a multiple technology system centered on BIM that integrates GIS, IoT, InSAR, RFID and digital twin. The case demonstrates that this technology can break through information barriers and achieve real-time environmental monitoring and dynamic optimization of construction. But there are still issues with insufficient data integration and scene adaptability. The research confirms that the integration of multiple technologies can reduce ecological disturbance without significantly sacrificing efficiency and provides a feasible path to solve the problem of green-efficiency balance.

There are three future development directions: 1. Combine BIM + GIS + IoT to build green evaluation indicators, quantify factors such as carbon emissions and soil and water conservation, and support the balance between efficiency and ecological dynamics. 2. Deepen the integration of BIM and GIS spatial analysis as well as IoT perception. In addition, conduct trials in more geological conditions and construction stages to solve the problems of data matching and scenario adaptation. 3. Promote modularization of technologies. Encapsulate functions like slope monitoring, vehicle positioning and progress visualization into standard modules. This allows construction units to combine them as needed with cost and scalability in mind. The goal is to provide universal support for the green and efficient construction of HSR.

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