International Journal of Education and Humanities
ISSN: 2770-6702 | Vol. 15, No. 3, 2024

From Theory to Practice: Challenges and Countermeasures for the Implementation of BIM and Intelligent Construction Technology

Xiongzhi Cao[1, *], Maoli Lan[2], Yaxin Li[3], Siyu Wang[1], Li Zhao[1], Yong Hou[1], Lian Li[1], Xinyuan Cao[1], Yang Xiang[1], Yujie Zhang[1]

[1] Chengdu Technological University, Chengdu 611730, China
[2] SI CHUAN HUA XIN (GROUP) CPA (LLP), Luzhou 646099, China
[3] China MCC5 Group corp.Ltd, Chengdu 610011, China
[*] **Corresponding Author**

Abstract: The rapid advancement of information technology has introduced Building Information Modeling (BIM) and intelligent construction technology as trans-formative tools in the construction industry. Despite their potential to significantly enhance efficiency, quality, and safety in construction projects, the practical implementation of these technologies is fraught with challenges. This paper explores the theoretical underpinnings of BIM and intelligent construction technologies and investigates the practical challenges encountered during their implementation. It provides an in-depth analysis of these challenges and proposes countermeasures to effectively address them, offering valuable insights for practitioners and stakeholders in the construction sector.Finally, through the study of the application of technology in actual projects, it is found that the combination of BIM and intelligent construction technology will improve the efficiency and quality of the construction process, reduce the waste and consumption of human resources, and improve the competitiveness and sustainable development capabilities of the project. It will promote the transformation and upgrading of the construction industry, promote scientific and technological innovation and industrial upgrading, and promote economic development and social progress. It will improve the safety and sustainability of construction, reduce accidents and environmental pollution during construction, and protect the health and safety of workers and the environment.

Keywords: BIM; Intelligent Construction; Implementation Challenges; Countermeasures.

1. Introduction

1.1. Background

In recent years, the housing and construction department has required the active use of innovative technologies such as BIM, IOT sensing, intelligent remote sensing, and construction robots to participate in design, construction quality and safety information monitoring, testing, and judgment analysis to improve the safety and quality control effects and economic benefits of engineering construction, Through a demonstration of this project, we will master the current advanced intelligent construction technology and carry out research on intelligent construction technology. At the same time, through the pilot application of this project, a project management model that can be replicated and promoted at this stage will be formed, and core technologies and innovation platforms for intelligent construction will be nurtured. The integration of BIM and smart building technology has become a key advancement in the construction industry, especially in the context of China's rapid urban development. BIM is a digital representation of the physical and functional characteristics of a building, providing a comprehensive platform for information management throughout the building life cycle. When combined with smart building technologies such as drone inspections, robotic construction, and the Internet of Things, BIM can significantly improve the efficiency, accuracy, and safety of construction projects.

1.2. Overview

In recent years, the construction industry has witnessed a technological revolution driven by the integration of BIM and intelligent construction technologies. BIM, with its capability to create and manage digital representations of physical and functional characteristics of projects, and intelligent construction technologies, which leverage the Internet of Things (IoT), artificial intelligence (AI), and big data, are reshaping traditional construction processes. Despite their promise, the implementation of these technologies presents several challenges [1-4].

Scholars from various countries have conducted relevant research on the theory and practical application of BIM and intelligent construction technology.

Zhou Xiaoping [5] applied the visualization, coordination and simulation features of BIM to architectural interior design, which has been widely used in the architectural field. It supplemented intelligent design from a new perspective of style consistency and formulated a more comprehensive intelligent design solution.

Waqar [6] explored the role of BIM in promoting sustainable development in small-scale construction projects and evaluated the impact of BIM on resource efficiency, energy performance, waste reduction, and collaborative decision-making in green buildings. The study found that there was a significant positive correlation between BIM adoption and early design optimization, energy efficiency analysis, material selection, life cycle assessment, waste reduction, and prefabrication.

Zhao Huizhi [7] independently developed a BIM construction process management platform, which combines construction progress, quality, safety, cost, green construction, etc. through BIM technology to carry out information management of the project, making it easier for owners and construction unit staff to apply the software, thereby greatly improving communication and usage efficiency, and providing important guidance for the project's construction process control and progress control.

Chen Yu [8] applied BIM technology to the overall design and construction of a cigarette factory. He guided the actual construction of the project by means of model building, visualization analysis of the building's internal space, conflict detection and optimization in pipe network design, and all-round dynamic management of data. He solved technical problems such as the design efficiency and construction quality of industrial buildings, and pipeline collision and leakage. This accelerated the progress of the project construction and saved project investment.

Waqar [9] conducted a comprehensive analysis of artificial intelligence and machine learning methods in the field of construction engineering, with particular emphasis on their practical applications, advantages, and limitations. Through academic literature and empirical investigations, he found that the integration of artificial intelligence and machine learning technologies can effectively solve problems such as cost overruns, project delays, and safety.

Actual projects have put forward higher requirements for intelligent construction equipment. The perfect application of BIM and intelligent construction technology in projects has brought considerable challenges to all parties involved in the construction, and has also promoted the further development of intelligent high-end software products [10]. Under the background of the coordinated development of data acquisition technologies such as 5G communication and industrial Internet, data computing technologies such as cloud computing and blockchain, and data analysis technologies such as deep learning and perception recognition, the digital transformation and intelligent upgrading of the construction engineering field have the support of data, computing power and algorithms [3]. In order to overcome the shortcomings of high-consumption and low-efficiency construction methods in the traditional construction field, intelligent construction that integrates modern information technology and construction technology has become an inevitable way. This transformation will not only help improve the production efficiency of the construction industry, but also promote the sustainable development of the industry and achieve higher levels of value creation.

2. Overview of BIM and Intelligent Construction Technology

2.1. Technical Theory

2.2. Building Information Modeling (BIM)

BIM is a digital representation of the physical and functional characteristics of a facility. It encompasses information throughout the entire life-cycle of a building, from initial design through construction and maintenance. BIM facilitates improved collaboration, accuracy, and efficiency by providing a shared platform for stakeholders to access and manage project information [3].

Benefits of BIM: (1)Enhanced visualization and simulation capabilities. (2)Improved accuracy in project design and documentation. (3)Streamlined communication and coordination among project stakeholders.

2.3. Intelligent Construction Technology

Intelligent construction technology incorporates advanced digital tools and systems such as IoT, AI, and automation to optimize construction processes. These technologies enable real-time data collection, analysis, and decision-making, thereby improving construction site management, safety, and efficiency [1, 3].

Components of Intelligent Construction: (1)IoT: Provides real-time monitoring and control of construction processes through connected sensors and devices [11]. (2)AI: Facilitates predictive analytics and decision support systems for better project management[2]. (3)Automation: Enhances precision and reduces labor costs through robotic systems and automated machinery [12].

3. Challenges and Countermeasures of Technology Implementation

3.1. Project Management Team

Intelligent construction has many complex subsystems and a wide construction area, which places high demands on construction area and personnel management. How to effectively organize the construction progress and personnel formation and deployment management will determine whether the overall construction progress of the project can be completed on schedule.

Countermeasures: Optimize personnel organization and management, improve personnel quality, conduct regular training, exchange and learn with scientific research institutions and universities, and establish an industry-university-research education base.

3.2. Data Management

A large amount of data will be generated during the intelligent construction process, including design data, construction data, test data, etc., which makes data management difficult.

Countermeasures: Strengthen the upgrade and application of the centralized information management and control platform to ensure the accuracy and security of data collection, storage and analysis. At the same time, cloud computing and big data technologies are used to achieve real-time monitoring and analysis of data.

3.3. Guaranteed Construction Period

Countermeasures: Regularly maintain and service the robot to reduce the possibility of failure. This includes cleaning the robot, checking the wear of key components, replacing worn parts, etc. Use sensors and monitoring systems to monitor the robot in real time to detect any potential signs of failure in time. This allows preventive measures to be taken before failure occurs and avoid delays. When a robot fails, a dedicated technician is required to quickly troubleshoot and repair it. To this end, it is recommended to train a professional maintenance team that can respond and resolve failures quickly. At the same time, it is required that the subcontractor can quickly organize a manual team to complete the performance of the contract.

3.4. Safety Work

Compared with traditional construction, robot construction adds new unstable factors, such as object impact and mechanical damage. How to ensure the safety of robot construction is the key factor for the safe implementation of the entire project. Countermeasures: (1) Strictly abide by relevant safety standards and regulations: Robot construction must comply with national and industry safety standards, including robot safety performance, operating procedures, safety protection measures, etc; (2) Conduct risk assessment and safety planning: Before the start of robot construction work, the first task is to conduct a comprehensive and detailed risk assessment of potential hazards, and then clarify the level and nature of the risk. Based on the assessment results, carefully plan and formulate detailed safety plans and response measures to ensure the stability and efficiency of the construction process; (3) Provide necessary safety protection equipment: To ensure the safety of the robot construction site, the work area must be equipped with necessary safety protection equipment. Including guardrails, safety warning signs, and safety nets. (4) Conduct safety training and operation guidance: Due to the professionalism and complexity of robot operation, it is crucial for operators to receive professional safety training. Operators can master the robot's operating procedures, deeply understand safety precautions, and master the response strategies and handling methods in emergency situations. (5) Install safety sensors and monitoring systems: Install safety sensors on the robot, such as collision sensors, photoelectric sensors, etc., so as to detect surrounding obstacles and personnel in a timely manner and take corresponding safety measures in a timely manner; (6) Perform regular maintenance and inspections: Regularly maintain and inspect the robot to ensure that it is in good operating condition and avoid safety problems caused by machine failures; (7) Establish an emergency stop and fault handling mechanism: Set up an emergency stop button and a fault handling mechanism at the robot construction site so that it can be stopped in time and take corresponding emergency measures in case of an emergency or failure; (8) Strengthen supervision and management: In order to ensure absolute safety during the robot construction process, a comprehensive and detailed supervision and management framework must be established. This system aims to monitor the construction process in real time, accurately identify and efficiently respond to potential safety hazards, thereby ensuring the safety and smoothness of the entire construction process.

3.5. Human-machine Collaboration

Robot construction needs to work in collaboration with manual construction, but since the coordination between robots and humans is not yet perfect, it is easy to have problems such as misoperation and conflict, which will affect the construction schedule. Countermeasures: Establish a communication mechanism between robots and manual construction personnel, strengthen training and exchanges, and improve the cooperation between the two parties. At the same time, introduce an intelligent collaborative management system to provide real-time monitoring and scheduling to ensure the smooth progress of construction.

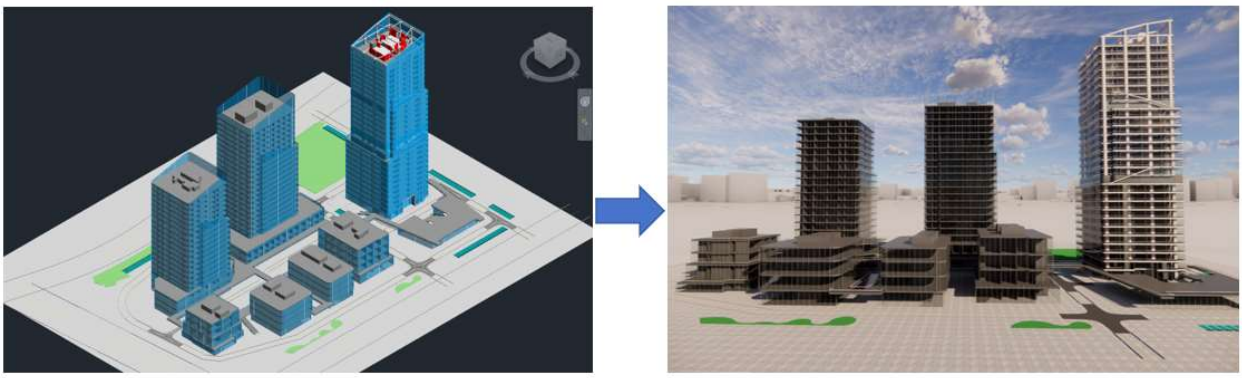
3.6. Finished Product Protection

Construction robots are relatively large machines. They may damage other work surfaces during operation, and completed work surfaces may be damaged by other work surfaces. Countermeasures: (1) Keep good records of on-site finished products, use auxiliary materials to cover and shield finished products, and use obvious signs to remind other work units; (2) Other professional finished products must be informed in advance when cross-operation is carried out to prevent unintentional destruction of other professional finished products; (3) During the construction process, for products that have been completed and have complete system functions, after strict acceptance and confirmation by the general contractor, we immediately start detailed planning and implementation of finished product protection. The core goal of this measure is to prevent potential damage and carefully maintain the superior performance and appearance quality of the product to ensure the stable progress of the entire construction project and the achievement of excellent results.

4. Case Studies

4.1. Project Overview

The project is located in Sichuan Province. The project integrates office buildings, commercial buildings, hotels and residences. After completion, it will become a new local landmark. This project plans to use the commercial area (Phase II) as the scope of intelligent construction implementation, as shown in Figure 1.



Phase II BIM Model　　Phase II BIM model rendering

Figure 1. BIM model diagram of the project

According to the characteristics of this project, the application of intelligent construction will be carried out mainly from two aspects: digital design and intelligent construction. In terms of digital design, BIM technology will be used as a carrier to carry out collaborative design and in-depth design to improve the accuracy and efficiency of design. In terms of intelligent construction, an intelligent project management platform will be established to achieve real-time monitoring and control of the construction site through the Internet of Things and intelligent construction robots. At the same time, virtual reality technology will also be applied to provide immersive construction experience and training to improve the skills of construction personnel, as shown in Figure 2.

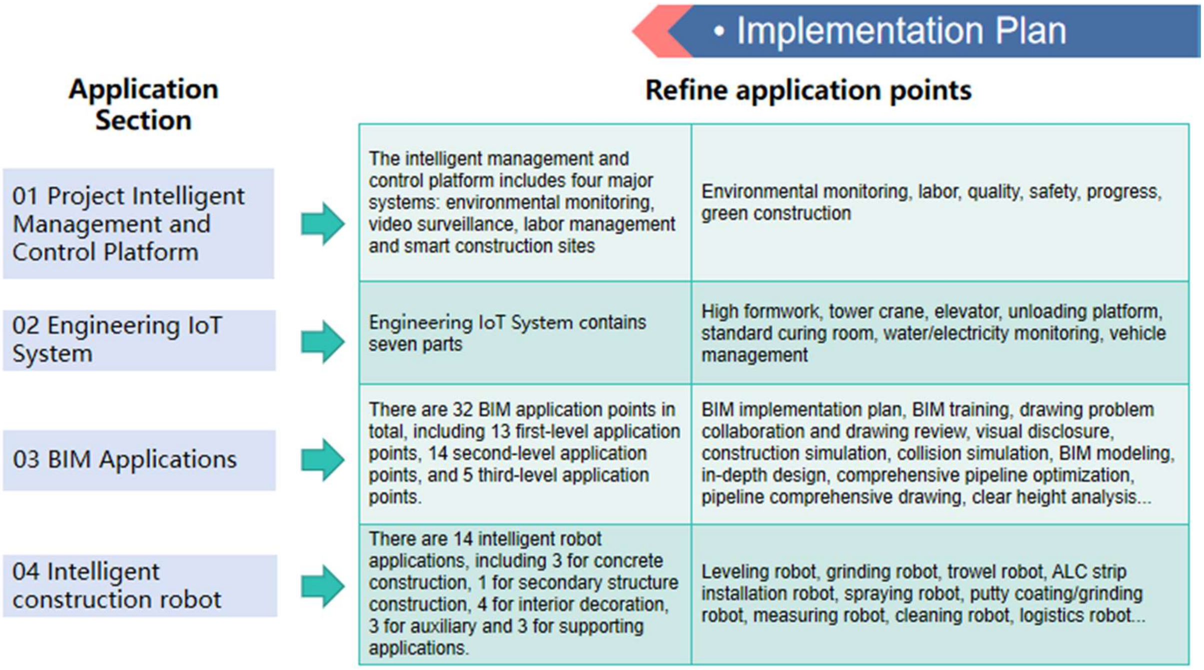


Figure 2. Application plan of BIM+ intelligent construction

4.2. BIM Design Application

BIM technology can realize the data generation, simulation and data carrying functions on the virtual side. Through BIM technology, construction projects can be collaboratively designed and deepened in a virtual environment to improve the accuracy and efficiency of the design. At the same time, BIM technology can also realize data circulation, so that design, construction and operation and maintenance personnel at different stages can share the same data and improve the efficiency of collaborative work.

The project adopts BIM full-process design, including BIM forward design, BIM collaborative design and in-depth application in the construction stage.

First, through BIM forward design, the whole process from scheme design to construction drawing design is completed, and important functions such as visual communication, three-dimensional collaboration, design optimization, green performance simulation and quality control are completed in the whole process design and project management.

Second, BIM collaborative design is carried out based on the establishment of a collaborative management platform. Through BIM collaborative design, all design disciplines and personnel can design on a unified platform, solve the errors, omissions, collisions and omissions caused by poor communication or untimely communication between current disciplines, truly realize the unity of all drawing information elements, realize automatic modification of other parts when one part is modified, and improve design efficiency and design quality.

Third, based on the completed BIM model, explore the in-depth application path in the construction stage, such as in-depth design, site use planning, visual disclosure, construction progress simulation, construction organization simulation, digital construction, construction quality and progress monitoring, material tracking, etc.

Through BIM full-process design, we explore the collaborative cooperation model of various units switching from traditional software design process to BIM design process, solve the communication problems in all aspects of BIM forward design, and provide experience and solutions for future project implementation.

4.2.1. BIM Collaborative Design

BIM collaborative design refers to the use of BIM technology to achieve seamless integration of design, construction and operation stages through collaboration and information sharing among all parties. It is an integrated design method that can improve design quality, reduce errors and conflicts, speed up project progress and reduce costs.

The implementation process of BIM collaborative design usually includes the following steps: First, determine the participants in collaborative design, including architects, structural engineers, mechanical and electrical engineers and other professional design teams. Then, establish a BIM model and integrate the design data of various disciplines into one model as shown in Figure 3. Next, coordinate and detect the model, analyze the model through software tools, and find and resolve design conflicts. Finally, optimize and improve the model, and adjust and modify it according to the needs of various disciplines.

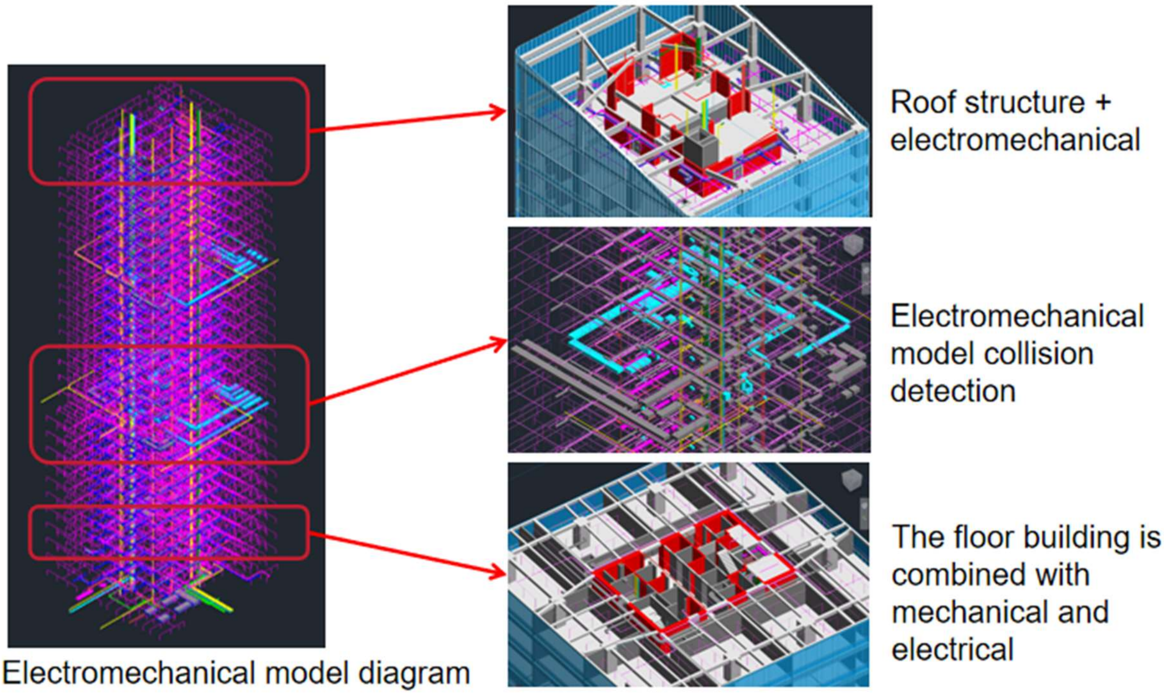


Figure 3. BIM integration model

In the project, the construction was organized through the use of BIM visualization to reduce the investment in temporary facilities; at the same time, combined with the application of handling robots, the handling route was reasonably planned to achieve the separation of man and machine. In terms of mold material transportation, BIM technology was used in combination with the on-site construction progress and material entry plan to simulate the entire material transportation process, fully considering the impact of temporary construction facilities, storage yards, equipment placement sequence, etc. on material transportation, realizing dynamic simulation of material transportation, improving on-site material transportation efficiency, and reducing the cost waste caused by on-site secondary handling.

4.2.2. BIM Performance Design

The project uses BIM to carry out performance design of the building's site environment, wind, light, sound, heat, etc. in the indoor environment, and simulates and analyzes fire evacuation. Through BIM performance design, the site environment of this project is optimized, the use quality of indoor and outdoor buildings is improved, and a scientific digital quantitative design is provided for the building to achieve energy-saving and low-carbon operation and maintenance. According to the established BIM model as shown in Figure 4, by using energy consumption software, test materials for green energy-saving and environmental protection requirements for decorative space, including professional space tests such as sound, light, electricity, ventilation, etc., and select reasonable decoration design solutions and decorative materials.

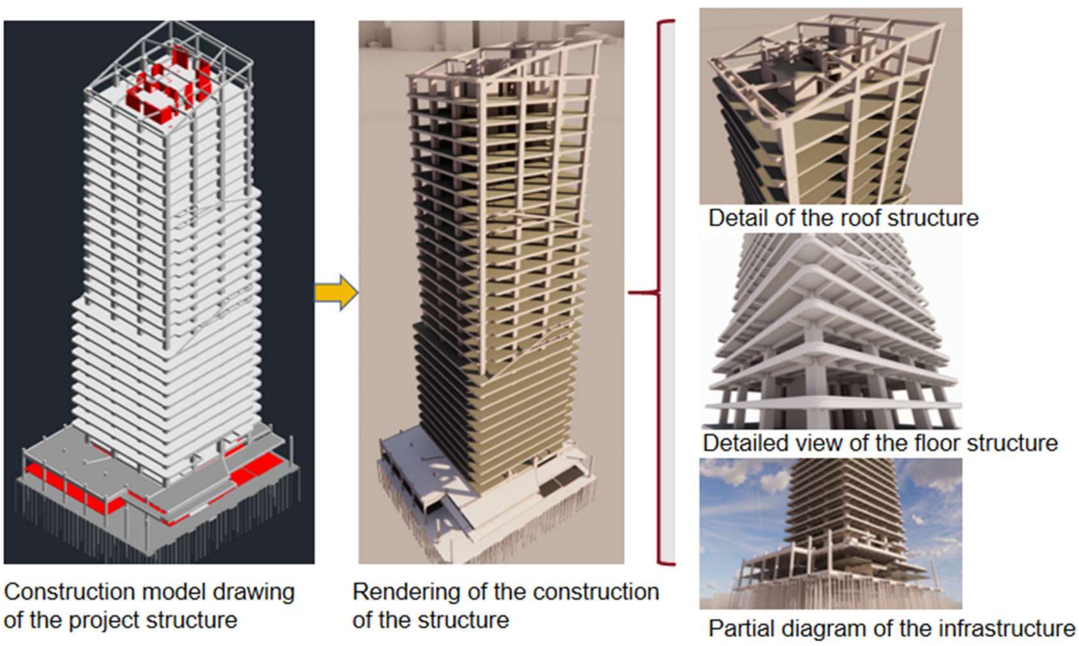


Figure 4. BIM integration model

4.2.3. BIM Deepening Design

The goal of BIM in-depth design is to upgrade the architectural design from a two-dimensional plan to a three-dimensional digital model (see Figure 5), and on this basis, to integrate and analyze multi-dimensional information. Through BIM in-depth design, all aspects of the building can be accurately simulated and analyzed, including structure, building physical properties, electromagnetically equipment, interior layout, etc. The integration and analysis of this information can help designers better understand and optimize the design plan and improve the sustainability and efficiency of the building.

In combination with the key and difficult points of the project, BIM technology is used to compare and select more than three construction plans. Each plan has at least two or more alternative plans, from which the best construction plan is selected through analysis and comparison. Detailed node deepening, collision optimization, and component parametric design are carried out for secondary structures, ALC strips, curtain walls, door and window railings, seismic brackets, etc. to meet the requirements of the specifications and guide construction.

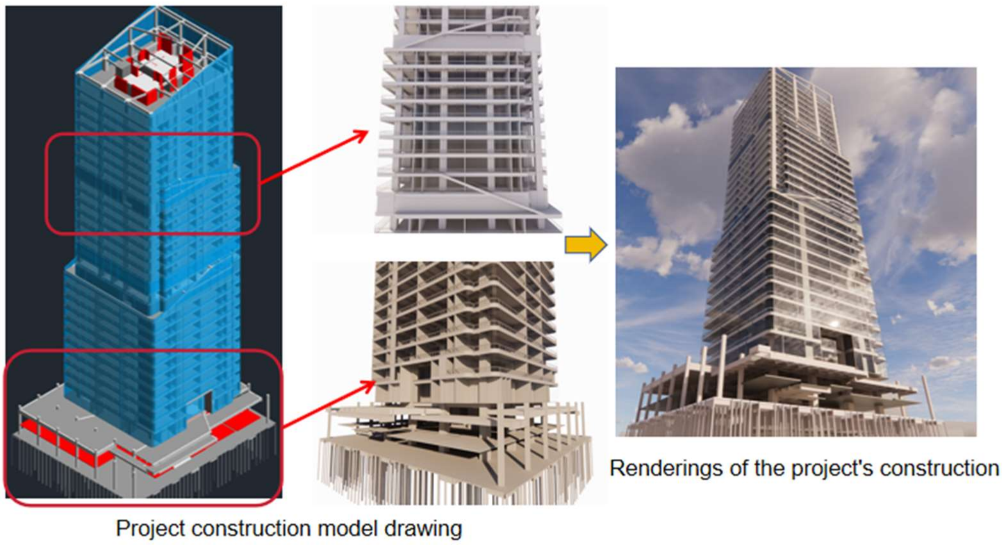


Figure 5. Three-digit model

4.3. Intelligent Construction Application

4.3.1. Smart Construction Site Platform

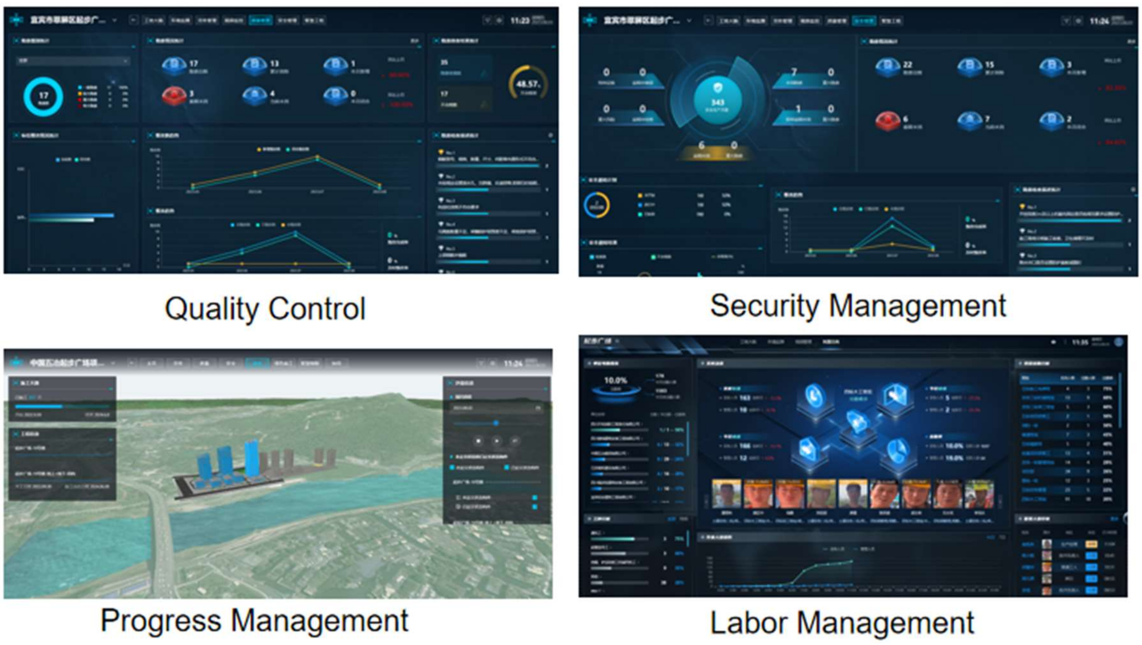


Figure 6. Smart construction site management platform

The project uses the Luban Smart Site Platform. By deeply utilizing new generation information technologies such as BIM, sensors, the Internet of Things, cloud computing, and big data, the project is integrated on the same platform, enabling the sharing of relevant application data and intelligent equipment collection information platforms, and centralized data display, analysis, and early warning; indicator data is centrally presented, making it easier for enterprises and project managers to understand and effectively supervise the on-site situation in a timely manner. It has changed the interaction mode, working mode, and management mode of on-site management of all parties involved in traditional construction sites, and realized the visualization and intelligence of project management.

The smart construction site platform includes: 1. Quality management: quality system, quality inspection, technical disclosure; assist project managers from system establishment, to the implementation of task responsibilities, to technical disclosure, to the investigation of quality hazards before they occur, to ensure project quality in all aspects; 2. Safety management: safety system, human-machine management, safety inspection, activities, hazard sources, dangerous projects, technical disclosure and other key focus contents. Realize data traceability, information sharing, accident warning, and preventive measures; 3. Progress management: Progress plan formulation, support online compilation; synchronously generate Gantt charts, intuitively reflect project progress deviations, provide early warnings for projects; and combine with BIM models to reflect project progress in three dimensions. 4. Labor management: By using the labor real-name system, standardize labor, safe labor, and efficient labor, and at the same time combine with BIM to achieve a two-way choice between traditional IoT solutions and BIM+ solutions, as shown in Figure 6.

4.3.2. Application of Intelligent Construction Robots

The concrete laser floor leveler, floor grinder and floor trowel used in the project are "adding fuel" to the construction progress. First, the laser floor leveler robot uses the intelligent laser leveling algorithm and wire-controlled chassis technology to achieve unmanned autonomous movement and high-precision leveling construction. After the initial setting of the concrete, the grinding robot uses the cruise technology and intelligent swing arm algorithm to carry out slurry lifting and finishing construction on the ground. The floor trowel robot trowels the ground before the final setting of the concrete. All three robots are small in size, flexible and easy to operate. They can be easily transferred in the complex working environment of the construction industry, and on-site managers can quickly get started and use them proficiently, as shown in Figure 7. It brings not only convenience to the construction industry, but more importantly, it can bring high efficiency, high precision and high returns to this project. At the same time, using robots to replace manual operations can effectively avoid casualties among workers on the construction site, which is a guarantee of safe construction and solves the problem of safe construction in the construction industry from the root.

Figure 7. Three machines are working in sequence

In addition to the use of the above-mentioned concrete robots, in combination with the project progress, the project will also use ALC strip installation robots, putty spraying robots, putty grinding robots, indoor spraying robots, measurement robots and building cleaning robots for combined construction, as shown in Figure 8. The use of robots will greatly improve construction efficiency and save labor costs. Precision construction will also bring standardization and high quality of construction quality.

Figure 8. Application of intelligent construction robots

4.3.3. Engineering IoT System

The engineering IoT system is mainly used to centrally manage the data of IoT equipment used in this project, including high-rise formwork monitoring, unloading platform monitoring, tower crane and hook visual monitoring, smart wearables, edge opening monitoring, environmental monitoring, water and electricity consumption monitoring, QR code application system, test block entry and exit management system, standard curing room monitoring, digital measurement equipment, etc. Through this system, the operation status of project-related equipment can be grasped in real time.

1) High formwork monitoring: By installing sensors and monitoring equipment, the inclination, deformation, bearing capacity and other parameters of the high formwork are monitored in real time, problems are discovered and measures are taken in time to ensure the safety and stability of the project.

2) Unloading platform monitoring: Use video monitoring equipment to monitor the unloading platform in real time, monitor safety hazards during the unloading process, and promptly discover and prevent accidents.

3) Visual monitoring of tower cranes and hooks: By installing cameras and sensors, the operating status of the tower crane, the load of the hook, and the safety of the surrounding environment are monitored in real time to ensure safety and efficiency during the construction process.

4) Smart wearables: Workers wear smart wearable devices to monitor their physical condition and work status in real time, provide timely health tips and warnings, and ensure the safety and health of workers.

5) Edge hole monitoring: Use video monitoring equipment to monitor the edge hole in real time, monitor the safety of the surrounding environment, and promptly discover and prevent accidents such as high-altitude falls.

6) Environmental monitoring: By installing environmental monitoring equipment, various environmental parameters are monitored in real time, and environmental pollution problems during the construction process are promptly discovered and solved to ensure a clean and healthy environment.

7) Water and electricity monitoring: By installing water and electricity monitoring equipment, the water and electricity usage of the construction site is monitored in real time, and energy waste and safety hazards are promptly discovered and solved, and energy utilization efficiency is improved.

8) Standard curing room monitoring: Use video surveillance equipment to monitor the standard curing room in real time, monitor indoor temperature, humidity, light and other parameters, and ensure the stability and accuracy of the standard curing process.

9) Digital measurement equipment: Use digital equipment to measure the construction site, and input the data to the central control system in real time to improve the accuracy and efficiency of the construction process.

Through the practical application of the engineering IoT system, real-time monitoring and data collection of the construction process can be achieved, improving the safety, stability and efficiency of the project, reducing construction risks, and providing strong support for the smooth progress of the project.

5. Conclusion

The goal of smart construction in actual engineering projects is to make the construction process intelligent, efficient and refined through the application of project integrated management and control platforms, engineering IoT systems, BIM applications and smart construction robots.

First, the project integrated management and control platform will integrate all aspects and data of the project to achieve information sharing and collaboration. Real-time monitoring of construction progress, quality, safety and other indicators will be carried out to achieve comprehensive management and control of the project and improve the efficiency and accuracy of project management.

Secondly, the application of the engineering IoT system will realize the intelligent management and tracking of building materials. Through the IoT technology, the supply, transportation and use of materials can be monitored in real time, reducing the waste and loss of materials, improving resource utilization and reducing project costs. BIM application will play an important role in the design, construction and operation of the project. Through BIM technology, the visualization and simulation of building information can be realized, potential problems can be discovered and solved in advance, changes and corrections during the construction process can be reduced, and construction efficiency and quality can be improved.

Finally, the application of intelligent construction robots will realize the automation and intelligence of the construction process. Robots can undertake some repetitive, dangerous and high-intensity work, improving construction efficiency and safety. At the same time, robots can also monitor the environment and quality of the construction site in real time through sensors and intelligent algorithms, provide accurate data and analysis, and help project managers make scientific decisions.

Acknowledgments

Fund projects: Chengdu Technological University Laboratory Open Fund (2023LOF016).

References

[1] Hu,Xi,Olgun, et al. An intelligent BIM-enabled digital twin framework for real-time structural health monitoring using wireless IoT sensing, digital signal processing, and structural analysis[J]. Expert Systems with Applications, 2024, 252: 124204.

[2] Rangasamy,Veerakumar,Yang, et al. The convergence of BIM, AI and IoT: Reshaping the future of prefabricated construction[J]. Journal of Building Engineering, 2024: 108606.

[3] Cui,Wei,Chen, et al. Application research of intelligent system based on BIM and sensors monitoring technology in construction management[J]. Physics and Chemistry of the Earth, Parts A/b/c, 2024, 134: 103546.

[4] Hu,Xi,Assaad, et al. A BIM-enabled digital twin framework for real-time indoor environment monitoring and visualization by integrating autonomous robotics, LiDAR-based 3D mobile mapping, IoT sensing, and indoor positioning technologies[J]. Journal of Building Engineering, 2024, 86: 108901.

[5] Zhou,Xiaoping,Ma, et al. BIM product recommendation for intelligent design using style learning[J]. Journal of Building Engineering, 2023, 73: 106701.

[6] Waqar,Ahsan,Othman, et al. BIM in green building: Enhancing sustainability in the small construction project[J]. Cleaner Environmental Systems, 2023: 100149.

[7] Zhao,Huizhi. The Application of Building Information Model in the Structural Design of Intelligent Buildings[J]. Procedia Computer Science, 2023, 228: 1047-1053.

[8] Chen,Yu. Design and optimization of construction equipment pipelines in cigarette factories based on BIM technology[J]. Ain Shams Engineering Journal, 2023, 14(8): 102054.

[9] Waqar,Ahsan. Intelligent decision support systems in construction engineering: An artificial intelligence and machine learning approaches[J]. Expert Systems with Applications, 2024, 249: 123503.

[10] Yasser Yahya Al-Ashmori,Idris Othman,Yani Rahmawati, et al. BIM benefits and its influence on the BIM implementation in Malaysia[J]. Elsevier Bv, 2020, 11(4): 1013-1019.

[11] Iqbal,Fahad,Ahmed, et al. BIM-IoT integration for remote real-time concrete compressive strength monitoring[J]. Ain Shams Engineering Journal, 2024, 15(7): 102863.

[12] Chen,Jiahao,Laokhongthavorn, et al. Exploring the knowledge system in building information modeling (BIM) technology for medical construction projects (MCPS): A bibliometric analysis and prospective direction[J]. Ain Shams Engineering Journal, 2024: 102897.