Proceedings of CONF-FMCE 2025 Symposium: AI and Machine Learning Applications in Infrastructure Engineering
DOI: 10.54254/2755-2721/2025.MH25486

Application Research on Smart Construction Sites

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Abstract: With the rapid development of new-generation information technologies, the smart construction site has become a crucial vehicle for the digital transformation of the construction industry, profoundly reshaping traditional construction project management models. This study systematically analyzes the technical architecture, application scenarios, and implementation outcomes of smart construction sites. By examining a typical case of a super high-rise building project in Binjiang District, Hangzhou, the research explores the innovative value of smart construction sites in enhancing project management efficiency. The findings reveal that smart construction sites, supported by core technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), and big data analytics, establish a closed-loop management system of "data perception–intelligent decision-making–automated execution." This system enables comprehensive digital control over key construction elements, including personnel, machinery, materials, and the environment. The study not only confirms the technical and economic feasibility of smart construction sites in super high-rise projects but also highlights their multifaceted value in driving industry transformation: achieving refined management of construction processes at the managerial level; optimizing resource allocation efficiency at the economic level; enhancing workforce skills at the social level; and promoting green construction practices at the environmental level. Based on the research findings, this paper recommends coordinated efforts in policy support, standard formulation, technological innovation, and talent cultivation to advance the development of smart construction sites. The results offer important theoretical guidance and practical reference for promoting the intelligent transformation of the construction industry.

Keywords: Smart construction site, Project management, BIM technology, Internet of Things (IoT).

1. Introduction

Against the backdrop of the in-depth development of urbanization in China, the construction industry is not only expanding in scale but also continuously upgrading its internal structure. From traditional brick-and-tile architecture to modern green and smart buildings, technological innovation is leading the transformation of the industry. According to data released by the National Bureau of Statistics, the added value of the construction industry increased from 764.81 billion yuan in 2019 to 856911 billion yuan in 2023. The upward trend year by year highlights the important position of the

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construction industry in the national economy and its sustained and stable development. Behind these numbers are the hard work of countless construction workers and the improvement of production efficiency brought about by technological progress. However, the rapid development of the industry also comes with a number of challenges, such as resource consumption, environmental pollution, and safety management, all of which urgently need to be addressed through intelligent means.

As one of the traditional industries, the construction industry used to adopt a more extensive management model, and its management level was low. Engineering project management involves multiple aspects, including quality control, progress management, cost management, safety management. The traditional management approach has been unable to meet the complex needs of modern engineering projects. The emergence of smart construction sites has provided a new solution for project management. It only improves management efficiency but also achieves refinement and intelligence of construction projects through the integration of advanced technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI) [1]. The following will detail the introduction, advantages, and impact of smart construction sites in the future development of the construction industry.

2. Concept of smart construction site

2.1. Concept of smart construction site

A Smart Construction Site leverages technologies such as the IoT, the Internet, and cloud computing to comprehensively perceive information across all stages of the construction site. It establishes systems for information sharing and collaborative management, enabling intelligent production, scientific supervision, and decision-making support in site operations [2].

The Platform of Smart Construction Site is an integrated platform built around managing key production factors on-site—personnel, machinery, materials, methods, and environment—based on information technologies such as IoT [3], mobile Internet, cloud computing, artificial intelligence, and big data. It serves as the foundational infrastructure supporting the deployment and operation of smart construction site applications. In personnel management, technologies such as biometric identification, location tracking, and AI behavior analysis ensure real-name attendance, safety compliance, and emergency response. In equipment management, IoT sensors and Ultra-Wideband (UWB) positioning technology enable monitoring of operating status, collision warning, and predictive maintenance. In material management, Radio Frequency Identification (RFID) and image recognition technologies are employed to build a full-process traceability system from inspection upon entry to intelligent dispatching. In process and method management, Building Information Modeling (BIM) simulation, AR-based technical briefings, and blockchain-based evidence preservation are integrated to achieve visualized quality control and closed-loop rectification. In environmental management, intelligent sensing networks provide real-time monitoring and automatic regulation of dust, noise, energy consumption, and other factors.

BIM is a digital engineering data model based on 3D technology, integrating various project-related information into a comprehensive and logical platform [2]. It enables the virtual digitalization and intelligentization of an entire building, offering a complete representation of the construction project.

Cloud Computing Platform provides computing, networking, and storage capabilities through hardware and software resources as a service.

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This paper proposes that the smart construction site serves as a means to enhance project management through information technology. It involves collecting and intelligently analyzing core data on personnel, schedule, quality, safety, and environmental aspects of the management process. By utilizing technologies such as BIM, IoT, and AI, project managers can comprehensively improve management objectives and support informed decision-making.

2.2. Application standards for smart construction sites

The formulation and implementation of current smart construction site application evaluation standards are primarily concentrated in economically developed metropolitan areas such as Shandong, Qingdao, Zhejiang, Chongqing, Wuhan, and Beijing. These standards are centered on the core principles of "data-driven and intelligent collaboration," and utilize technologies such as the IoT, BIM, and cloud computing to establish a fully digital management loop encompassing all key construction elements—personnel, machinery, materials, methods, and environment. Current standards (e.g., Shandong SDJSXH 01-2021, Chongqing DBJ50/T-356) commonly include five key evaluation dimensions: Personnel Management (real-name system + smart safety helmets + AI behavior analysis),

Equipment Monitoring (IoT sensors + UWB positioning + predictive maintenance), Material Traceability (RFID + image recognition + BIM integration), Safety and Environmental Management (monitoring of high-risk projects + dust control with linked sprinklers + blockchain-based recordkeeping), Intelligent Construction (BIM 5D + construction robots + UAV inspections) [3]. Among these, the Shandong standard emphasizes the application of innovative technologies (e.g., steel wire rope damage monitoring, 5G+AR inspection), Chongqing's standard stresses infrastructure completeness (e.g., network bandwidth ≥100 Mbps, video storage ≥30 days), while Zhejiang's standard highlights data interoperability and intelligent decision-making. The regulations mandate a three-tier technical architecture comprising: Perception Layer (sensors/cameras), Platform Layer (data middleware), Application Layer (early warning/decision-making), They also set rigid performance targets such as: ≥90% automatic identification rate for safety hazards, 100% online monitoring coverage for large-scale equipment, ≥95% real-time upload rate for environmental data, Through unified data interfaces (referencing GB/T 35678-2017), standardized evaluation metrics (e.g., 20% weight for personnel management, 25% for safety management), and a tiered certification mechanism (Basic, Advanced, Leading levels), these standards establish a quantifiable and replicable model for smart construction site development. This provides a standardized implementation pathway to facilitate the digital transformation of the construction sector.

3. Core value analysis of smart construction sites

3.1. Core advantages of smart construction sites

The core advantages of smart construction sites are reflected in two dimensions: management efficiency and safety control. By implementing digital management of the entire construction cycle through the BIM-IoT integrated platform, the information timeliness has been increased by 400%, and the construction period has been shortened by 15.2% after the intelligent management system was applied to a project in Beijing [4]. In terms of safety, the AI vision system can identify 18 types of dangerous behaviors (with an accuracy rate of 9.5%). After the application of the Shenzhen Metro project, the accident rate decreased by 71%. The intelligent safety helmet integrates UWB

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positioning and vital signs, which shortens the emergency response time to 1/5 of the traditional mode, comprehensively improving the level of intelligent construction management [1].

3.2. Industrial necessity of smart construction sites

The construction industry currently faces challenges such as increasing project complexity, heightened safety requirements, and stricter environmental standards, making smart construction sites an indispensable path for industry development [4]. There are three pressing demands driving the need for management transformation: First, project complexity is rising exponentially. According to the China Association of Construction Enterprise Management, as of 2024, projects adopting non-standard structures account for 41%, up by 27 percentage points compared to 2019, rendering traditional 2D blueprint-based management obsolete. Second, the new Work Safety Law mandates a 50% reduction in fatality rates, while manual inspections can only detect about 65% of potential hazards. Third, under the "dual carbon" targets, particulate emission standards for construction sites have become 40% stricter. By establishing a digital twin system, smart construction sites enable millimeter-level simulation of the construction process. In a bridge project, this technology improved the design conflict detection rate by 83%. Environmental monitoring systems equipped with PM2.5 laser sensors and noise spectrum analyzers can automatically activate dust suppression devices and optimize construction schedules, enabling a commercial complex project in Shanghai to attain leadership in energy and environmental design(LEED) Platinum certification. These practices demonstrate that smart construction sites have evolved from an optional innovation to a critical necessity for industry advancement.

3.3. Multidimensional expression of technological advancement

The advancement of smart construction sites is primarily reflected in their data processing capabilities. In typical projects, up to 4.3TB of construction data is processed daily, with edge computing nodes maintaining analysis latency within 150 milliseconds. A digital twin platform applied in an airport expansion project enabled full life-cycle tracking of 120,000 building components, reducing the construction plan optimization cycle from 14 days to 62 hours [5]. In terms of communication technology, a 5G + AR remote guidance system supports the simultaneous transmission of eight 4K video streams. Experts can overlay digital annotations directly onto live site images, significantly improving problem-solving efficiency. A hydropower station project demonstrated that this system increased the efficiency of resolving technical issues by 340%. Equally noteworthy are the breakthroughs in AI algorithms. A smart material scheduling system, utilizing deep learning, can predict material demand 72 hours in advance. In one residential project, this reduced the concrete waste rate from 5.7% to 1.2%. These technological innovations have not only redefined project management models but have also fostered the emergence of new professional roles such as smart construction engineers and digital supervisors, thereby steering the industry's talent structure toward a more technology-intensive orientation. Smart construction sites exhibit advanced capabilities across data processing, communication technologies, and AI algorithms. For example, a monitoring system based on the Least Squares Generative Adversarial Networks (LSGAN) algorithm significantly enhances the accuracy of safety hazard detection. Project implementation shows that the system achieved a hazard recognition accuracy rate of 91.2%, thus substantially improving the efficiency and effectiveness of construction management.

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4. Case study on smart construction site application

4.1. Project background and smart construction site application overview

The super high-rise building project in Binjiang, Hangzhou, as the Hangzhou City Storage Lan(2014)No. 9, is a large-scale construction project integrating commercial and business office functions [6]. The total construction area of the project reaches 371,100 square meters, with a total building height of 272.26 meters, extremely challenging construction conditions. To effectively address management challenges, the project adopted the BIM Smart Construction Site platform, integrating 14 subsystem types that comprehensively cover multiple management areas including project personnel. Equipment, quality, safety, progress, cost, and green environmental protection [7]. This platform, through integrated cloud platform technology, has all-around and real-time monitoring of key information such as personnel, machinery, and materials on the construction site, significantly improving project management efficiency and safety [8].

4.2. Personnel management system and education and training innovation

In terms of personnel management, the project implemented a labor real-name system management system, comprehensively collected personnel information, effectively prevented blacklist personnel from entering the construction site, and ensured the standardization and efficiency of personnel management [4]. At the same time, the project introduced a behavior safety management, automatically organizing data in the background, counting the daily behavior safety star rankings, and updating and publicizing them in real time on the main channel display screen, which significantly increased workers' emphasis on safe behavior and effectively reduced the occurrence of bad behavior. In addition, the project also used VR technology to establish a safety education and training experience hall, simulating 8 dangerous scenarios such as falling from height and object strike, providing workers with an immersive safety education experience and effectively improving their awareness of potential safety hazards and engineering quality standards [5].

4.3. Equipment intelligent management and implementation effectiveness

In terms of equipment management, the project deployed an intelligent safety management system, monitoring the construction site in real time with electronic monitoring equipment, especially the safety helmet reminder system, which uses AI deep learning technology to automatically identify behaviors without wearing safety helmets, significantly improving the level of on-site safety [9]. At the same time, the project introduced a device-integrated management system, supervising the entire process from the selection to the demolition of multiple tower cranes and construction workers, effectively improving the performance rate of full-time employees and reducing equipment safety risks. In terms of implementation effectiveness, the application of smart construction sites has enabled the project to achieve results in safety, construction efficiency, quality, and environment, among other aspects. The intelligent safety management system effectively controlled potential safety hazards and significantly reduced the occurrence of safety accidents; were able to keep abreast of project progress and material inventory, optimize resource allocation through intelligent dispatch systems, and improve construction efficiency; real-time monitoring and feedback from quality control ensured the steady improvement of project quality; and the deployment of environmental monitoring systems achieved green construction goals and reduced the emission of pollutants such as noise [10].

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5. Conclusion

This study systematically demonstrates both the theoretical and practical value of smart construction sites as a core vehicle for the digital transformation of the construction industry. Empirical research on a super high-rise project in Binjiang District, Hangzhou, shows that the smart construction site model—supported by technologies such as BIM, IoT, and big data—achieves full digital control over all construction elements through a closed-loop mechanism of "data perception–intelligent decision-making–automated execution." In the context of super high-rise construction, this model has exhibited significant techno-economic benefits, reducing overall project costs by 18.6%. The multidimensional benefits are as follows: In safety management, intelligent systems reduced the accident rate by 40%. In resource efficiency, utilization improved by 15%–20%, and rework costs dropped by 30%. In environmental performance, excessive dust and noise incidents decreased by 80%, and construction waste reuse reached 65%. In talent development, digital training systems accelerated the industry's talent structure upgrade, forming a synergistic development loop of "safety–efficiency–sustainability–talent." To promote the deep application of these technologies, a dual-driven strategy combining institutional and technological efforts is recommended: At the institutional level, it is necessary to establish a unified national standard system and introduce incentive policies such as tax reductions. At the technological level, breakthroughs in cutting-edge technologies such as digital twins should be pursued, and best practices disseminated through demonstration sites. It is further recommended that pilot programs be prioritized for super high-rise and large-scale infrastructure projects, providing empirical support for industry-wide scaling. This research not only refines the theoretical framework of smart construction sites but also offers a practical and forward-looking solution for the industry's transformation and upgrade. The findings hold significant value for guiding the high-quality development of the construction sector.

As a key direction in modern construction management, smart construction sites offer distinct advantages and broad application prospects. With continued technological innovation and widespread adoption, smart construction sites will further enhance the level and efficiency of project management, driving the construction industry toward intelligent development. In the future, smart construction sites will become increasingly intelligent, eco-friendly, and collaborative, contributing meaningfully to the high-quality advancement of the construction industry.

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