Proceedings of CONF-FMCE 2026 Symposium: Smart City and Infrastructure Engineering
DOI: 10.54254/2755-2721/2026.CH35560

Systematic Application of Smart Construction Site Technology in Construction Safety Management

Xuan Wang

School of Architectural Engineering, Jinling Institute of Technology, Nanjing, China
wx2278726615@outlook.com

Abstract. Construction accidents occur frequently, and traditional on-site management methods lack adequate risk foresight. Manual supervision has a narrow scope and a slow response, and thus cannot meet the safety requirements in a changing construction environment. Smart construction sites use digital technology to promote the improvement of construction safety. Most of the current research has focused on individual technologies or functions of platforms and has failed to systematically integrate the analysis of the technological framework, application results and practical problems. Based on the above analysis, this paper establishes the core concept and structural components of a smart construction site as a new safety management model, which consists of three levels: an all-encompassing management platform, Building Information Modeling (BIM) technology, and a six-tier Internet of Things (IoT) control system. Based on the above foundation, the New Shandong Provincial Science and Technology Museum project is taken as an example, and the deployment method and working logic of a smart construction site in specific construction scenarios across four dimensions are analyzed. The results show that this model has achieved the following management objectives: shortened the schedule, reduced material costs, and decreased quality rework. Finally, the paper also analyzes the practical constraints of smart construction site promotion, such as unstable equipment, inconsistent data standards and an unreasonable safety investment structure, and puts forward targeted improvement suggestions. By systematically examining the technical framework, application effects and improvement directions of smart construction sites, this paper offers references for the digitalization of construction project safety management.

Keywords: Smart Construction Site Technology, Building Information Modeling, Internet of Things, Construction Safety Management

1. Introduction

With the development of society and the economy in recent years, construction has expanded significantly, and thus construction safety is now a problem that affects all construction projects. However, recently, there have been frequent construction safety accidents in China, causing serious damage to economic efficiency, reducing the effectiveness of construction work, and impeding the continuous development of the construction industry. Based on the above statistics, in 2019, the accident rate was about 5.31% higher than in 2018, and the proportion of fatalities among those

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.CH35560

injured in accidents reached 7.62% [1]. The main reasons for the frequent accidents are that the construction projects are becoming more complex, there is a lack of safety awareness among some construction workers, and on-site supervision is insufficient.

Therefore, the older model of safety management has shown some deficiencies under this pressure, such as slow response and lack of integration, making it difficult to meet the changing needs of contemporary construction. Digital and intelligent technologies have been applied to construction sites, and a 'smart construction site' refers to the concentration and organized application of these digital technologies in the area of construction management. It is not a single technology, but a new kind of construction safety management that uses a management platform as its carrier, Building Information Modeling (BIM) technology for data foundation, and the Internet of Things (IoT) as its sensory network.

The implementation of smart construction site technologies optimizes the on-site safety management system. These targeted, around-the-clock, and digitalized safety control methods address the current safety management challenges at Chinese construction sites more effectively than traditional approaches. Smart construction sites can reduce delays and financial losses caused by safety accidents in the project, and also ensure the safety of construction workers on site. Therefore, this paper will focus on the technical measures and application results of smart construction sites, as well as existing problems and future directions, to demonstrate how they help improve the safety of construction work, and offer some references for safety management in similar construction projects.

2. Core technical measures for construction safety management in smart construction sites

2.1. Smart construction site management platform

The seven general divisions of functions for a smart platform of construction site management are: project information, personnel management, special equipment management, safety and quality management, environmental management, material management, and special applications [2].

The main content of the project information section is basic information about the project; standardized searches for project-related documents are available here, as well as details on the principal personnel in the project team.

The first module of personnel management is responsible for face recognition, real-name labor registration records, precise attendance tracking and payroll calculation, real-time personnel location tracking, and safety training. Organize real-name labor registration to reduce labor-related disputes, protect the security of workers' wages, and promptly inform relatives of an accident. At the same time, facial recognition functions and related mobile applications address attendance problems in some special work environments. According to the actual circumstances of the application, suitable position-tracking technology will be selected to monitor the movement of staff in real time, obtain location data and path information, and analyze how the staff are distributed in different areas and at different times. When a person enters an area they are not allowed to be in, the system will trigger an alarm as specified in the security alert plan for restricted Areas. The above functions have tackled the most severe problems in personnel management at the source and are now capable of a quick investigation after a safety accident to help the relevant department carry out rescue work. Safety training increases people's awareness of their own safety, and using app technology to record the training history motivates them to participate more frequently and thus helps prevent accidents.

Supervision of the management of special equipment covers tower cranes and hoists. Sensors have been installed on the high-risk equipment of tower cranes to connect them with the control

DOI: 10.54254/2755-2721/2026.CH35560

center and enable operator identification. At the same time, the system monitors the real-time operating status of equipment to prevent accidents such as tower crane tilting, equipment collision, and overload.

A General Module of the Smart Construction Site Management Platform is Safety and Quality Management. It covers video supervision, safety facilities, assessment of safety risks, monitoring of deep excavations, steep slopes, tall buildings, temperature monitoring of large-scale concrete pouring, intelligent measurement and on-site inspection, vehicle access control, etc. To ensure the safety of people and property at the construction site, Closed-Circuit Television (CCTV) cameras will be set up in various places to monitor the movement of people and vehicles, construction work and the progress of the project. Risk management is strengthened, operational efficiency is optimized, and the speed of emergency response is improved. For high-risk construction projects such as deep excavations, steep slopes, high formwork and mass concrete, the platform can be used to conduct visual supervision, real-time data analysis and issue alerts for any abnormal behavior of the structure to prevent safety accidents. Staff can use mobile phones to report on-site safety and quality problems by text, pictures, sound and video. The platform automatically generates rectification orders and issues them to the responsible units, ensuring that issues are resolved in a closed-loop manner. At the same time, intelligent devices can be employed for fine-grained quality supervision of the construction process, and all work vehicles, commuter vehicles, and visitor vehicles must be individually registered at the construction site.

Environmental management includes dust, noise and severe weather warnings, and now proactively prevents them. Reduce noise to protect the physical and mental health of staff, lower the risk of accidents caused by severe weather alerts, and thus protect the occupational health and lives of construction workers and local residents.

To prevent the use of poor-quality materials and pollution caused by non-compliant materials, stricter management of materials will be introduced to lower the risk of construction accidents.

The Featured Applications' section introduces new technologies for construction progress simulation and digital handover during the infrastructure stage. These applications will increase the efficiency of work for construction personnel and reduce construction time and staff workload.

2.2. Building Information Modeling technology

BIM technology digitally represents the functional and physical attributes of a project entity throughout its entire life cycle, including design, construction, operation, and maintenance. As the digital core of intelligent construction, BIM technology enables visual and collaborative management throughout the whole construction process of building projects, with its application covering all stages including construction preparation, on-site work and process control [3]. At the heart of the purpose for applying BIM in smart construction sites is to build a three-dimensional, visualized information-sharing environment for safety management [4]. Establish an all-encompassing management system for intelligent construction sites based on BIM technology to improve the digitalization, visualization and organization of project management, and build an orderly central hub of construction projects. The system organization can reduce errors in planning, design, construction and operation at all times to control project risks. It can control the pollution of the environment and promote green development at the same time. To promote the brand, smart construction sites and BIM technology can be used to attract investor support and spread through the media, thereby strengthening the enterprise's brand image and competitive strength.

DOI: 10.54254/2755-2721/2026.CH35560

2.3. The Internet of Things

IoT provides the technology for real-time sensing at the construction site of a smart building. The six levels of its safety control system are: the perception layer, the transmission layer, the data layer, the support layer, the application layer and the user layer.

The lowest level of the safety system includes all kinds of sensing devices, such as surveillance cameras, sensors, Radio Frequency Identification (RFID), video and image recognition, positioning systems and laser scanning equipment. These devices will continuously monitor the conditions around hazard sources and changes in the environment in real time to detect any safety risks that may occur at any time, especially in the stages where damage to vital links in the production process is serious.

The Transmission Layer is responsible for transmitting data in the whole-platform system. Both Wired and Wireless networks can be used. Front-end sensors can transmit collected data to the data layer in real time and reliably over both wired and wireless networks. With the development of technology, new network technologies such as 5G have been released to address some problems at construction sites, such as the construction of a special monitoring environment, difficulties in cabling, and weak network signal reception [5].

The Data Layer will provide a central database for all sensor data from the various subsystems, manage master data in a single place, and handle data exchange with the Application Layer. The data in the database provides basic data support for the smart construction site to evaluate and handle various safety problems. With an increase in the volume of data in the database, the smart construction site will be able to handle all sorts of problems and fluctuations more scientifically and reliably.

The support layer consists of various public services and shared resources required by the system for operation, such as unified identity authentication and access control, data fusion and computation, standardized Application Programming Interface (API), network security safeguards, including firewalls and Virtual Private Network (VPN) gateways and Web Geographic Information System (WebGIS) services. The Support Layer is connected to the Data Layer and the Application Layer. The support layer converts raw data into standardized services for use by upper layers.

Under the umbrella of the intelligent construction site, the seven components of the application layer include project management, personnel management, special equipment management, safety and quality management, environmental management, material management, and other special applications. The application layer is the direct interactive interface for managers of the smart construction site system, and it converts large volumes of data obtained from the lower layers into concrete operational instructions and visual information. It can be used to collect data and implement management decisions in the safety management system.

The User Layer generally connects to the government's regulatory platform, enterprise-level platforms, and project-level platforms. The three different platforms have separate ports for connecting, and thus can meet various requirements; some information that is sensitive to privacy and security will be sent to government platforms through a special channel.

DOI: 10.54254/2755-2721/2026.CH35560

3. Application outcomes and practical challenges in construction safety management at smart construction sites

3.1. Application outcomes in typical projects

The Shandong Science and Technology Museum is located in the core area of the Western New Town in Jinan, Shandong Province, and its development ideas are innovation, coordination, green development, openness and sharing. The ancillary facilities in the project are as follows: an exhibit maintenance area, an audiovisual zone and server room, civil defense facilities, an underground car park and equipment rooms, with a total gross floor area of approximately 80,000 square meters [6].

The construction process of this project was based on the idea of a smart construction site and divided into five parts: a data repository, collaborative management, overall system functions, multi-platform applications, and IoT data. A data repository will be built to house all the construction-stage data. All construction drawings and architectural models have been uniformly compiled and archived; the entire set of documents is fully traceable and accessible at any time during the project to prevent disorganization and loss of traditional construction records, providing a complete basis for the final project acceptance inspection. The online collaborative management system of this project will serve as a centralized communication platform for all involved parties. Construction, supervision, design and site teams use the same platform for operation, and regular drawing revisions, technical coordination and on-site correction work are all carried out online. Any construction problems that occur at the construction site will be promptly recorded and uploaded online; at the same time, the progress of rectifying these problems will be tracked continuously until they are fully resolved. The general management functions of this project are to meet the demands of all stages in the construction work at the site and exercise overall control over the construction schedule [7]. The system can reasonably plan the speed of construction according to actual circumstances at the construction site, standardize on-site construction practices, and comprehensively address the main problems of on-site quality control, safety management, and material dispatch to ensure the smooth progress of the entire project. Multiple devices are supported by the management system, and all roles have met their work requirements. Staff can use their mobile phones at any time to view the site for an inspection tour and promptly record the construction conditions of the construction site. Organize documents, approve plans, collect data, and so on at the office terminal for more flexible and efficient work. Finally, the smart construction site safety management system for this project achieved good results. The whole project was finished 63 days earlier than planned, material costs were reduced by 2.16 million yuan, and major quality-related rework incidents were almost eliminated; it has been named one of the nation's first benchmark projects for smart construction sites [6].

3.2. Practical challenges facing the roll-out of smart construction sites

Most of the existing smart construction site systems are based on static evaluation methods and have certain shortcomings; as a result, they are not suitable for assessing and addressing problems at construction sites. Changes in personnel and the actual operating conditions of machinery are not updated in the management system in time, leading to significant information lag and reduced production efficiency; thus, problems cannot be addressed promptly. The current smart construction site system lacks high-precision safety assessment criteria and cannot adapt flexibly to various circumstances [8]. Under extreme weather conditions, the sensors at the perception layer may malfunction, and the equipment may fail. Moreover, the costs of developing smart construction sites,

DOI: 10.54254/2755-2721/2026.CH35560

operating and maintaining equipment, and technological upgrades are too high; at the same time, there is a low willingness to invest in research and development for technology and safety measures, so smart equipment upgrades and data processing capabilities are limited [9]. There is a shortage of multi-skilled professionals in digital security management as well. Safety training generally covers only basic operations, and there is no specific instruction on smart devices and data risk management; thus, the system's capabilities for early warning, self-recovery, and emergency response remain relatively weak.

4. Recommendations for promoting smart construction sites

The following recommendations address the challenges identified above. To address information delays, smart construction sites can leverage next-generation communication technologies such as 5G to enhance data transmission speed and network stability. Thus, it will be possible to transmit the collected data to the smart construction site management center in a timely manner and improve the work efficiency of the devices. Given the specific environmental and weather conditions in different areas, relevant personnel can conduct surveys of the dry and humid climatic conditions in these places to develop instruments and equipment that are suitable for such special circumstances. Whether construction work can proceed normally during equipment repair should also be considered [8]. Safety education and training should be organized for staff to reinforce safety awareness. Incentives, such as awards for high-performing employees and certificates based on training results, can also be introduced. In the recruitment stage, the professional skills of staff should be considered, and investment in training all-around digital security management specialists should be increased [10]. In the early days of a project, some measures should be taken to address potential safety accidents in advance and prevent a situation of disarray in the event of an accident.

5. Conclusion and outlook

5.1. Conclusion

The construction industry is a core part of the economy, but in recent years, safety accidents at construction sites have been occurring frequently, and traditional management methods are no longer suitable for complex construction environments today. Many digital technologies have been applied to build an all-new system for on-site safety management at smart construction sites, such as integrated management platforms, BIM, and the IoT. The seven functional modules of the integrated management platform are introduced; at the same time, BIM is employed for 3D visualization across the entire life cycle of a construction project, and IoT technology will be used to collect, transmit and apply on-site data in layers. This paper examines an actual construction project of the Shandong Science and Technology Museum. The project has fully implemented the smart construction site system, established online cooperation channels, maintained complete digital construction records, and thus reduced the construction period, lowered material costs, and significantly decreased major quality-related rework; it has fully demonstrated the practical value of digital management. At the same time, many problems still exist in the industry-wide application of this approach. Outdoor monitoring equipment is exposed to weather conditions, has a relatively high investment cost for hardware and software, there is a significant shortage of professionals with expertise in both construction safety and digital technology, and the capacity for emergency response within the system is limited. In light of the above problems, 5G technology can be employed to enhance the speed of data transmission; long-lasting monitoring devices specifically designed for the

DOI: 10.54254/2755-2721/2026.CH35560

construction environment can be developed; an all-round management team will be cultivated; and all-weather safety and emergency response plans will be established before the start of construction. The above measures will help to continuously improve the efficiency of safety management and control at smart construction sites.

5.2. Outlook

Smart construction sites are still in their infancy at present; although they have shown some rapid development, they have not yet achieved full maturity. Specifically, they still have considerable deficiencies in terms of adaptability to dynamic working conditions, cost-effectiveness of safety investments, and the cultivation of multi-skilled talent, which restrict the full realization of the technology's potential and large-scale application in the construction industry. In the future, as 5G communication technology spreads widely, the real-time performance and stability of information transmission will be significantly improved, and thus the problem of insufficient network coverage at construction sites, especially in areas such as deep excavations and underground spaces, is expected to be fundamentally solved. At the same time, to break down the data silos among subsystems and achieve true integration of BIM models, IoT sensors and management platforms, an industry-wide unified cross-system data standard and interface specification need to be established. The future development of smart construction sites will require continuous optimization of the technology and, at the same time, the coordinated progress of industry standards, talent cultivation, investment mechanisms, to build a strong and stable safety protection system for construction.

References

[1] Huang, J. C., Xu, K., & Dong, Z. B. (2021). Research and implementation of the system architecture for a smart construction site management platform. *China Energy Engineering Group Jiangsu Electric Power Design Institute Co., Ltd., 42*(11), 25–30.
[2] Han, Y., Sun, H., Li, Y. H., & You, S. D. (2018). System architecture and implementation of smart construction sites. *Science & Technology Progress and Policy*, (24).
[3] Liu, Y. L. (2026). Research on the application of intelligent construction technology in building engineering construction. *Intelligent Building & Smart City*, (S1).
[4] Qiu, C., Kang, W. C., Deng, Y. S., Jiang, S. W., Tian, H., & Qin, X. H. (2022). A discussion on the application value and development trends of BIM+smart construction sites. *China Construction Third Engineering Bureau Group Co., Ltd., 43*(S02), 275–278.
[5] Yan, X. J., & Zhang, S. (2021). Empowering smart construction site construction with 5G technology. *Installation*, (10), 11–13.
[6] Li, J., & Zhu, D. S. (2021). Sunlight and shadows • starlight at night – Integrated design of the new Shandong science and technology museum project. *Zhongnan Architectural Design Institute Co., Ltd., 027*(1), 34-39.
[7] Fei, T., & Chen, Y. T. (2022). Research on the construction system of complicated form building based on smart collaboration – A case study of new Zhengzhou Museum project. *Architectural Journal*(S2).
[8] Zhang, T. (2021). Application development and future prospect of smart construction site. *Installation*(10), 03-06.
[9] Guo, C. B., Yan, W. D., Li, Y. P., & Li, L. H. (2024). A study on safety vulnerabilities in smart construction sites based on system dynamics. *Journal of Safety Science and Technology, 20*(8), 42-50.
[10] Wang, T., Huang, X. P., Wu, Q. Q., Zhang, P., Xu, Z., & Fang, B. W. (2025). Application research on temperature control system of mass concrete for bridge foundation under smart construction site scenario. *Highway*(5), 92-99.