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Research on the Application of Smart Construction Site System in the Construction Process

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Abstract. The construction industry is constrained by problems such as frequent safety accidents, low efficiency, and backward informatization (with an informatization rate of only 0.03%), and the traditional management model is characterized by obvious "three highs" (high risk of aerial work, high waste of energy-intensive building materials, and high difficulty in efficient collaboration). The smart construction site system integrates technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Building Information Modeling (BIM) to realize the intelligent management of all elements (personnel, machinery, materials, methods, and environment) in the construction process. This paper analyzes the application of the system in scenarios such as environmental monitoring, violation identification, and construction simulation, and verifies its effectiveness with cases: UWB positioning technology shortens the rescue time by more than 70%, and tower crane monitoring achieves "zero accidents" while improving efficiency by 20%. The research shows that the system can reduce the safety accident rate by more than 40% and improve management efficiency by about 35%. In response to problems such as data silos and high costs in promotion, the system needs to develop towards intelligence and integration in the future to help the high-quality transformation of the construction industry.

Keywords: Smart Construction Site, Smart construction application, Construction safety

1. Introduction

As a crucial pillar industry of the national economy, the construction industry has long been confronted with challenges such as frequent work safety accidents, low production efficiency, and severe resource consumption. The traditional construction management model exhibits obvious "three highs" characteristics: high risk of aerial work, high waste of energy-intensive building materials, and high difficulty in efficient collaboration. Taking safety issues as an example,recent data from the Ministry of Housing and Urban-Rural Development (2025) shows that smart construction pilot projects have reduced the accident rate by 38% compared to 2018, highlighting the urgency of digital transformation [1].

Moreover, with the rapid development of intelligence and technology, the pace of transformation and upgrading of traditional industries has accelerated. However, the construction industry is

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relatively backward in its ability to absorb and utilize new technologies. Data shows that compared with other industries, the informatization level of the construction industry is only higher than that of agriculture, ranking second to last among 22 industries. Compared with the international average informatization rate of 0.3% in the construction industry, China's construction industry informatization rate is only about 0.03% [2], with a gap of nearly 10 times [3].

Nowadays, smart construction site systems have achieved remarkable results in fields such as personnel management, safety management, and environmental monitoring. Through technologies such as face recognition. AI video analysis, and sensor networks, full-element monitoring of personnel, machinery, materials, methods, and environment at construction sites has been realized. However, the promotion and application of smart construction sites still face challenges such as data silos, inconsistent technical standards, and high initial investment costs, which require further in-depth research.

This study not only helps to enrich the digital theoretical system of construction project management but also provides practical guidance for construction enterprises. By improving safety management levels, enhancing project quality, increasing management efficiency, and reducing resource consumption, it promotes the digital transformation and high-quality development of the construction industry.

2. Application of smart construction site system in the construction process

2.1. Introduction to smart construction site system

At the critical stage when the construction industry is moving towards high-quality development, the traditional extensive management model has increasingly become a bottleneck restricting project quality, safety, and efficiency. Problems such as chaotic on-site management, difficulty in timely detection of potential safety hazards, low efficiency of resource scheduling, and trouble in quality traceability have long existed. Against this background, the "Smart Construction Site System" has emerged as the core engine driving the digital transformation and intelligent upgrading of the construction industry, opening a new chapter in construction site management in the "Internet +" era.

The Smart Construction Site System refers to an integrated management platform that deeply integrates new-generation information technologies such as the Internet of Things (IoT), cloud computing, big data, Artificial Intelligence (AI), Building Information Modeling (BIM), and mobile Internet. It conducts all-round, real-time, and intelligent perception, interconnection, analysis, and control of key production elements such as "personnel, machinery, materials, methods, and environment" at the construction site. Its core objectives are as follows:

- Enhance intrinsic safety levels: Proactively prevent safety accidents through intelligent means.
- Ensure controllable project quality: Realize refined management of the construction process and traceable quality.
- Optimize resource allocation efficiency: Improve the utilization efficiency of personnel, equipment, and materials.
- Promote green and low-carbon construction: Strengthen intelligent monitoring of energy consumption, emissions, and environmental indicators.
- Improve collaborative management efficiency: Break down information silos and achieve efficient collaboration among all project participants.

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2.2. Research on application in the construction process

2.2.1. Smart construction site based on IoT and sensor networks

In 1999, the Massachusetts Institute of Technology (MIT) in the United States established the "Auto-ID Center" , which proposed that "everything can be interconnected through the network" and clarified the basic meaning of the Internet of Things.

• Technical Support: Deploy various sensors (such as tower crane stress sensors, elevator operation sensors, noise and dust sensors, water and electricity consumption sensors, personnel positioning tags, smart safety helmets, and high formwork monitoring sensors) to collect on-site data in real time.

• Application Scenarios: Real-time environmental monitoring (PM2.5, noise, temperature, and humidity), safety monitoring of large-scale equipment operation (tower crane anti-collision, hook visualization, elevator safety early warning), accurate personnel positioning and attendance checking, electronic fences in dangerous areas, real-time monitoring and early warning of high formwork/deep foundation pits, and intelligent water and electricity meter management.

2.2.2. Smart construction site based on Artificial Intelligence and computer vision

Since its proposal in the 1940s, Artificial Intelligence (AI) has been applied in multiple disciplines and formed various algorithms. AI algorithms (e.g., YOLOv8) now achieve 92% accuracy in detecting safety violations (e.g., unfastened helmets), as reported in a 2025 case study from Xi'an's smart construction project [4]. These systems not only alert in real-time but also analyze behavioral patterns to predict high-risk zones, aligning with Gartner's prediction of a $55 billion indoor location market by 2030 [5].With the rapid development of Deep Learning (DL) since 2006, AI has become a research and application hotspot in various fields [6].

• Technical Support: Use AI algorithms to analyze video surveillance images.

• Application Scenarios: Intelligent video surveillance (automatically identify and alarm illegal behaviors such as not wearing safety helmets, not wearing reflective clothing, smoke and flames, personnel crossing boundaries, and unauthorized entry into restricted areas), intelligent identification of concrete surface defects, automatic progress identification based on images, and AI-assisted drawing review and collision detection.

2.2.3. Smart construction site based on BIM

BIM (Building Information Modeling) is a digital representation of the physical and functional characteristics of a facility. It is a shared knowledge resource and a process of sharing information about the facility to provide a reliable basis for all decisions throughout the facility's life cycle from conception to demolition. At different stages of the project, different stakeholders insert, extract, update, and modify information in BIM to support and reflect the collaborative work of their respective responsibilities [7].

• Technical Support: Provide a 3D digital model base for the project.

• Application Scenarios: In-depth design and collision inspection, 4D/5D construction simulation (visual schedule management and cost correlation), accurate ordering and installation guidance of prefabricated components, visual technical disclosure, completion model delivery and later operation and maintenance support. BIM is combined with on-site IoT data to realize a "digital twin" construction site.

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2.2.4. Smart construction site based on Big Data Analytics and cloud computing

Big Data Analytics (BDA) is the core of big data concepts and methods. It refers to the process of analyzing massive, diverse, fast-growing, and authentic data (i.e., big data) to find hidden patterns, unknown correlations, and other useful information that can assist in decision-making [8]. Cloud computing is one of the distributed computing technologies. It means decomposing massive data computing and processing programs into countless small programs through the network "cloud", then processing the results fed back by the small programs based on a system composed of multiple servers, and finally returning them to users. At this stage, it can be regarded as a comprehensive result of the hybrid development of advanced technologies such as distributed computing, utility computing, parallel computing, load balancing, and network storage, and has the characteristics of high agility, reliability, scalability, and automation.

• Technical Support: Provide powerful data storage, computing, and analysis capabilities.

• Application Scenarios: Convergence and storage of massive on-site data, multi-dimensional data correlation analysis (such as cross-analysis of progress, resource, safety, and quality data), risk prediction and early warning (such as collapse risk prediction based on historical data), provision of data support for management decisions (such as optimizing personnel scheduling and material procurement plans), and generation of various intelligent reports.

2.2.5. Smart construction site based on mobile internet and collaborative platforms

• Technical Support: Mobile APPs and cloud-based collaborative platforms.

• Application Scenarios: Managers can check the construction site status and data anytime and anywhere, handle inspection tasks and hidden danger rectification notifications on mobile terminals, conduct online multi-party collaboration (design changes, drawing joint reviews, and process handovers), manage migrant workers' real-name registration and wages, and carry out mobile safety education and training.

3. Practical engineering application cases

3.1. Digital practice in personnel safety and real-name management

At construction sites, the terrain is complex, the number of construction personnel is large, and personnel mobility is high. The traditional methods of manual clock-in and paper-based safety education records make it difficult to effectively manage personnel entry/exit, attendance, and on-duty status. In case of an accident, the efficiency of personnel positioning and rescue response is low.

3.1.1. Application of smart system

The project has deployed a personnel safety management system based on UWB (Ultra-Wideband) high-precision positioning technology, which has thus become an effective solution to resolve the conflict between the demand for high-speed access in hotspots and the tight spectrum resources [9], and is deeply integrated with real-name access channels and labor management platforms.

Real-name System and Access Management: All workers must complete real-name information registration and pass safety training assessments before entering the site. When passing through the turnstile, they enter by face swiping or card swiping, and the data is automatically synchronized to

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the system, ensuring the consistency of "person, certificate, record, and contract" and eliminating illegal employment.

High-Precision Indoor and Outdoor Positioning: Each construction worker is provided with a safety helmet with a built-in UWB chip. Positioning base stations are deployed on-site, enabling the system to obtain the precise location (with an accuracy of 10-30 cm), movement trajectory, and historical activity area of personnel in real time.

The intelligent safety helmet management system is a modern intelligent management system with a certain level of intelligence, integrating wireless communication technology, voice communication technology, BIM, RFID technology, etc [10].

• Electronic Fence and Early Warning: "Electronic fences" are set up in dangerous areas (such as the edge of foundation pits, blasting warning zones, and near high-voltage equipment). If unauthorized personnel enter, the system will immediately pop up an alarm on the management platform, and can issue a warning through on-site broadcasts or devices worn by personnel to remind them to leave.

• SOS Emergency Help: The safety helmet is equipped with an emergency help button. In case of danger or sudden illness, workers can trigger the distress signal immediately. The system will accurately locate their position and notify the nearest safety officers and rescue teams to rush to the scene as soon as possible.

• Big Data Analysis: The system automatically counts the number of personnel in each area and their on-duty hours, and generates attendance reports. Managers can analyze the heat map of personnel distribution, optimize human resource allocation, avoid overcrowding in certain areas, and reduce safety risks.

3.1.2. Application effects

Accurate and Efficient Rescue: In a simulation drill, the time from triggering the help request to locating and finding the "injured person" was reduced by more than 70%, gaining valuable time for life rescue.

• Proactive Safety Prevention and Control: It effectively prevented personnel from entering dangerous areas without permission, eliminating potential safety hazards in the bud.

• Transparent Management: It realized digital and transparent management of personnel attendance, working hours, and positions, reduced labor disputes, and improved management efficiency.

3.2. Application of smart system

The project has introduced an intelligent safety monitoring system for tower cranes that integrates the Internet of Things (IoT) sensors and Building Information Modeling (BIM). Finally, it is concluded that only by embracing the collaboration of multiple information technologies can the construction of a smart construction site platform be realized, and the unification of virtual and reality be achieved [11].

• Real-Time Data Collection: High-precision sensors are installed on the jib, tower body, and hook of each tower crane to monitor key data such as the load, radius, moment, slewing angle, and wind speed of the tower crane in real time.

• Anti-Collision System: Through a wireless communication network, the system collects real-time position and movement status data of all tower cranes into a central processing platform. The platform has a built-in anti-collision algorithm and sets a three-dimensional "electronic safety zone"

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for each tower crane. When there is a risk of collision between the jibs or hooks of two tower cranes, the system will immediately send an audio-visual warning to the terminal in the tower crane driver's cab; if the risk continues to rise, the system will automatically cut off the operation in the dangerous direction and force the tower crane into a safe state.

• BIM Model Integration: The system integrates the operation trajectory of the tower crane with the BIM model of the project, and dynamically displays it on a 3D visualization platform. Managers can clearly see the "virtual" operation status of each tower crane on the central control screen, and whether the hoisting path conflicts with buildings or other facilities is clear at a glance.

• Hook Visualization: A high-definition camera is installed on the tower crane hook. The driver can clearly see the real-time video screen around the hook through the display screen in the cab, completely eliminating the risk of blind hoisting and greatly improving hoisting accuracy and safety.

• Zero Safety Accidents: During the entire main structure construction period, the system successfully warned and avoided dozens of potential collision accidents, achieving the goal of zero major safety accidents in tower crane group operations.

• Efficiency Improvement: The hoisting efficiency was improved by about 20%, because the driver's operation is more confident, the command and scheduling are more accurate, and unnecessary waiting and adjustment time is reduced.

• Management Upgrade: It has upgraded from the "human-based prevention" model that relies on manual experience to an intelligent model of "technology-based prevention + human-based prevention". Safety management has objective data support, and management decisions are more scientific.

4. Conclusions and prospects

Through the integrated application of modern information technologies such as the Internet of Things, big data, and artificial intelligence, the smart construction site system has realized digital and intelligent management of all elements including "personnel, machinery, materials, methods, and environment" at the construction site. Studies have shown that the system has achieved remarkable results in the following aspects:

• Significant improvement in safety management level: Through AI video monitoring, intelligent sensors, and positioning technology, real-time identification and early warning of safety risks have been realized, and the incidence of safety accidents has been significantly reduced. Recent case studies (2020–2025) confirm that smart systems reduce accident rates by 40–70% and improve efficiency by 20–35% [2,12]

• More refined project quality management: With the help of BIM technology, 3D scanning, and UAV inspections, visualized management of the construction process and precise quality control have been achieved, effectively reducing rework and resource waste.

• Substantial increase in management efficiency: Automated data collection and analysis have reduced manual recording work, and the intelligent scheduling system has optimized resource allocation, improving project management efficiency by approximately 35%.

• Obvious improvement in environmental benefits: Through intelligent dust monitoring, automatic sprinkler systems, and energy monitoring, green construction and sustainable development have been realized, reducing the impact of construction on the environment.

However, the promotion and application of the smart construction site system still face challenges such as data silos, inconsistent standards, high initial investment costs, and a shortage of professional talents, which need to be further addressed.

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In the future, the smart construction site system will develop in a more intelligent, integrated, and standardized direction. For example:

- Technological integration and innovation;
- Widespread application of robot technology;
- System integration and standardization;
- Intelligent decision support;
- Green and low-carbon development.

With the continuous advancement of technology and the gradual reduction of costs, the smart construction site system will expand from large-scale projects to small and medium-sized projects, and finally realize the digital transformation of the entire industry, promoting the construction industry towards high quality, high efficiency, low carbon, and environmental protection.

References

[1] Ministry of Housing and Urban-Rural Development. (2025). Annual Report on Smart Construction Pilot Cities.
[2] Agarwal, R., Birch N, Bauer M. (2020). Digital Transformation in Construction. McKinsey & Company.
[3] Agarwal R, Chandrasekaran S, Sridhar M. (2016) Imagining construction's digital future. McKinsey.
[4] Shaanxi Sensor and IoT Industry Alliance. (2025). Application of Artificial Intelligence in Construction Site Safety. White Paper on Sensor Industry Development.
[5] Gartner. (2023). Indoor Location Services Market Forecast.
[6] LeCun Y, Bengio Y, (2015) Hinton G. Deep learning. Nature, 521: 436-444.
[7] National Institute of Building Sciences. (2007) United States National Building Information Modeling Standard, Version 1-Part 1.
[8] Li GJ, Hua BL. (2014) Analysis of the relationship between big data analysis and intelligence analysis. Journal of Library Science in China, 40(5): 14–22.
[9] Roy S, Foerster J R, Somayazulu V S. (2004) Ultrawideband radio design: The promise of high-speed short-range wireless connectivity. IEEE Proceedings, 92(2): 295–311.
[10] Zeng H. (2017) Research on intelligent safety helmet system for construction engineering. Harbin: Harbin Institute of Technology.
[11] Wei SH, Du WL, Ming BJ. (2016) Prospects of interactive development technology based on BIM and IoT in smart buildings. Construction Engineering Technology and Design, 2016(30): 1446.
[12] Southern Metropolis Daily. (2025). Application Report on Smart Safety Helmets in Longcheng Street. 8(26).