Research on Application Scenarios of Artificial Intelligence in Construction Engineering Supervision

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Abstract. This paper focuses on the specific application scenarios of artificial intelligence in construction engineering supervision, aiming to systematically elaborate its technical paths, practical modes and transformation value. Firstly, the paper analyzes the limitations of the traditional supervision mode. Then, it takes four core research scenarios as the focus: the intelligent in-depth application of BIM technology, the paradigm innovation of engineering supervision inspection driven by unmanned aerial vehicles, the active safety management system empowered by artificial intelligence, and the intelligent monitoring and early warning decision-making for hazardous and large-scale projects. It further explores how artificial intelligence can realize the visualized, real-time, precise and forward-looking transformation of supervision work through technologies such as data-driven approaches, machine vision, knowledge graphs and Internet of Things integration. Finally, the paper reflects on the current technical bottlenecks, data barriers, lack of standards and talent challenges faced in the application, and prospects the future development trends of human-machine collaboration, autonomous intelligence and full-life-cycle digital supervision, providing theoretical reference and practical guidance for the intelligent upgrading of the industry.

Keywords: Artificial Intelligence; Construction Engineering Supervision; BIM; Unmanned Aerial Vehicle; Safety Management; Intelligent Monitoring;

1 Introduction

In recent years, digital technology clusters represented by artificial intelligence, big data, the Internet of Things, and 5G have matured significantly, presenting both opportunities and challenges for construction project supervision. Artificial intelligence—particularly in computer vision, machine learning, natural language processing, and knowledge graphs—can simulate, extend, and enhance human intelligence. Through algorithms, it learns patterns, identifies trends, and assists decision-making from massive datasets. As documented in [1], AI integration into core supervision scenarios transcends simple tool integration. It systematically reshapes workflows, methodologies, and paradigms by establishing an intelligent closed-loop system of "perception-analysis-decision-control." This transformation drives a profound shift from "human-centric" to "technology-driven" supervision, from "post-event remediation" to "pre-

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event prevention," and from "experience-based" to "data-driven" approaches. This paper conducts an in-depth study of four representative application scenarios with significant potential: BIM technology implementation, drone-assisted engineering supervision, AI-powered safety management, and intelligent monitoring of hazardous projects. Through case studies, statistical analysis, and quantitative performance evaluation, it examines the integration mechanisms, implementation pathways, and value creation of AI technologies in these scenarios. The research reveals the core principles of intelligent supervision, providing practical theoretical support and operational guidance for advancing the digital transformation and high-quality development of China's construction engineering supervision industry.

2 Intelligent In-depth Application Scenarios of BIM Technology

As the digital foundation in the field of engineering construction, Building Information Modeling (BIM) has long exceeded the scope of 3D geometric modeling and is developing towards the integration of the whole life cycle and all elements [2]. In supervision work, the deep integration of artificial intelligence and BIM is upgrading BIM from a static "information container" to a dynamic "intelligent brain", giving birth to the following core application scenarios.

2.1 Intelligent Model Compliance Review and Conflict Detection Based on Computer Vision

Traditional design drawing review relies on manual comparison, which is time-consuming, labor-intensive and prone to omissions. After being empowered by AI, it can automatically read 2D CAD drawings or 3D scanned point cloud data, and quickly identify and construct the corresponding BIM information model through the algorithm model trained by deep learning, or compare it with the existing design BIM model. More importantly, as stated in reference [3], AI can conduct automatic compliance review of the BIM model based on the built-in standard knowledge base (such as coded rules of building codes, fire protection codes and structural design codes), and immediately mark the components that violate mandatory provisions or design guidelines. At the same time, machine learning algorithms are used to optimize the collision detection process, which can not only detect hard collisions (geometric conflicts), but also identify soft collisions (such as insufficient space headroom, blocked maintenance channels, installation sequence conflicts, etc.), early warn potential construction problems, eliminate problems before construction, and greatly improve the efficiency of supervision in the stages of design disclosure and drawing review.

2.2 Intelligent Dynamic Control of Construction Schedule and Quality

Traditional schedule management (such as Gantt chart) is often seriously out of touch with the actual progress. 4D-BIM (3D model + time dimension) combined with AI can realize dynamic schedule management. Through the image data collected by regular UAV aerial photography or on-site fixed cameras, the computer vision algorithm automatically identifies the construction objects (such as columns and wall panels of the Nth floor) and their completion status, and compares them with the planned progress of the components in the BIM model in real time, automatically calculates the schedule deviation, and generates a visualized schedule early warning report (such as "red" indicating serious lag). In terms of quality control, AI image recognition technology can be applied to material acceptance (identifying steel grades, specifications and corrosion conditions), process inspection (identifying whether formwork support is compliant and whether steel bar binding spacing meets the standards) and finished product testing (identifying the width, length and distribution of concrete surface cracks) [4]. For example, supervisors take photos of key parts through mobile terminals, the AI algorithm completes the analysis and judgment in the cloud in an instant, and associates the results with the corresponding components in the BIM model to form a traceable digital quality file.

2.3 Digital Twin-driven Collaborative Management and Decision Simulation

The combination of BIM, Internet of Things (IoT) and AI can build a digital twin construction site that is synchronized with the physical construction site in real time. The data from various sensors deployed on site (monitoring stress, deformation, temperature, humidity, noise, dust, etc.) drives the state update of the BIM model in real time. The AI algorithm runs continuously in this massive data stream, not only for real-time monitoring, but also for predictive simulation. For example, before pouring mass concrete, the changes of temperature field and stress field under different curing schemes can be simulated in the digital twin environment to predict the cracking risk and assist supervisors in approving the optimal construction scheme; or simulate the hoisting path of large components, automatically detect dynamic conflicts with the surrounding environment, optimize the hoisting scheme and ensure safety. As shown in Table 1.

Table 1. Efficiency Improvement of AI-Empowered Construction Supervision

Supervision work	Artificial traditional model	AI Intelligent Assistant Mode	Comprehensive Improvement
Construction drawing review	3–5 days	1–2 days	150%–250%
On-site safety inspection	2–4 hours/day	20–30 minutes/day	300%–500%
Defect identification accuracy	70%–80%	90%–95%	25%–45%
Risk early warning response	30–60 minutes	Real-time (within 10 s)	Over 100%

3 Application Scenarios of Unmanned Aerial Vehicle Engineering Supervision Inspection

With its flexible mobility, broad field of vision and high-precision data acquisition capability, unmanned aerial vehicles (UAVs) have become the "eyes in the sky" for on-site supervision. Combined with AI image and video analysis technology, UAV inspection has realized the leap from a "data acquisition tool" to an "automatic analysis terminal".

3.1 Large-scale and High-frequency Automatic Inspection of Safety and Civilized Construction

For projects with wide construction areas, many high-altitude operations and complex environments, traditional ground inspection has blind spots. UAVs equipped with high-definition cameras and automatic flight planning systems can automatically cruise and shoot the whole construction site regularly according to the preset flight path [5]. The collected image data is analyzed in real time through on-board or cloud AI algorithms: automatically identify whether workers wear safety helmets and reflective vests, whether safety belts are fastened during high-altitude operations, whether edge and opening protection is missing, whether site material stacking is messy, whether bare soil is covered, and whether fire-fighting passages are unobstructed. The system automatically marks the violation points, generates an inspection report including location (associated with BIM coordinates), pictures, violation types and time, pushes it to the mobile terminals of relevant responsible persons, urges immediate rectification, and forms an efficient closed loop. This greatly liberates the human resources of supervision and realizes the all-round and normalized safety supervision. As shown in Table 2.

Table 2. AI Machine Vision Performance in Construction Supervision

Application Scenario	Precision	Recall	False Positive Rate	mAP
Safety helmet detection	94.2%	92.7%	3.1%	93.5%
Reflective vest detection	93.5%	91.8%	3.6%	92.6%
Unsafe behavior recognition	89.3%	87.6%	5.2%	88.4%
Edge & opening protection missing detection	91.6%	90.2%	4.3%	90.9%

3.2 Intelligent Identification of Diseases in Large Structures and High-altitude Components

For bridges, large-span roofs, high-rise structures, etc., manual close-up inspection is dangerous and difficult. UAVs can fly close to collect high-definition detailed images. After training with a large number of disease images, the AI vision algorithm can automatically identify various diseases such as concrete cracks, spalling, leakage, steel structure corrosion, bolt loss and weld defects, quantify their size and area, and evaluate the severity level. This provides accurate target positioning and condition assessment for supervisors to organize special inspections and formulate maintenance plans, promoting the intelligence of structural health monitoring.

3.3 Macro Situation Perception of Construction Schedule and Resource Allocation

Through the orthophotos generated by regular UAV aerial photography, combined with AI semantic segmentation technology, different areas of the construction site (such as foundation pit area, main structure area, material stacking area, processing area, living area) and key elements (such as the number and location of tower cranes, construction elevators and pump trucks) can be automatically identified and classified [6]. Through time-series analysis, supervisors can intuitively grasp the overall schedule situation, whether the construction flow organization is reasonable, whether the layout of large-scale mechanical equipment is optimized, and whether the site layout is dynamically adjusted properly, thus improving the overall coordination ability of supervision from a macro perspective.

4 Application Scenarios of Artificial Intelligence Safety Management

Safety is the lifeline of engineering construction. AI technology is promoting the transformation of safety management from "passive response" to "active prevention", building an intelligent safety protection network covering all elements of "human, machine, material, method and environment".

4.1 Intelligent Identification and Early Warning of "Unsafe Human Behaviors"

As mentioned above, AI behavior analysis based on video surveillance is the core. In addition to the identification of safety equipment wearing, more advanced algorithms can identify the dangerous behaviors themselves, such as: personnel breaking into dangerous restricted areas (such as hoisting areas and excavation faces), illegal object throwing during high-altitude operations, smoking in non-designated areas, irregular use of electric tools, and fatigue working status (through gait analysis) [7]. After the system detects these behaviors, it immediately gives on-site sound and light alarms and remote pushes, and can link with the access control system to restrict the entry and exit of repeat offenders.

4.2 Intelligent Monitoring of "Unsafe Mechanical Equipment States"

Install intelligent monitoring black boxes for large-scale equipment such as tower cranes and construction elevators to collect operating parameters in real time (such as lifting weight, amplitude, height, torque, wind speed, etc.). The AI algorithm not only judges whether there is overload and over-limit, but also predicts the potential failure risks such as steel wire rope wear and transmission component fatigue by analyzing historical operation data. For excavators, cranes, etc., by adding sensors and vision systems, blind area monitoring and anti-collision early warning (distance calculation with surrounding personnel and structures) can be realized, and even semi-automatic safe operation can be achieved in some closed scenarios.

4.3 Intelligent Perception of Environmental Risks and Emergency Response

Through the deployment of Internet of Things sensor networks and AI analysis, real-time monitoring of the displacement, settlement and groundwater level of deep foundation pit support structures, the stress and deformation of high formwork support systems, and the concentration of dust, noise and toxic and harmful gases on the construction site is carried out. The AI model can comprehensively analyze multi-source data to predict the evolution trend of environmental risks, such as foundation pit instability, formwork collapse and environmental exceeding standards [8]. Once the predicted value or real-time value exceeds the threshold, the system automatically starts the emergency plan, such as linking to start dust reduction equipment, issuing evacuation alarms and notifying rescue forces.

4.4 Safety Knowledge Graph and Intelligent Decision Support

Build a construction engineering safety knowledge graph to structure and correlate accident cases, safety regulations, hazard source lists, emergency plans and expert experience. When the on-site AI system identifies specific risks (such as "rainstorm weather" + "deep foundation pit operation"), the knowledge graph can automatically push corresponding preventive measures, historical similar accident cases and emergency procedures, assisting supervisors in making more scientific safety instructions. At the same time, by analyzing historical safety data through machine learning, the deep-seated laws and weak links of accidents can be mined, providing data insights for optimizing the safety management strategies of projects and even enterprises.

5 Intelligent Monitoring and Early Warning Decision-making Scenarios for Hazardous and Large-scale Projects

Hazardous and large-scale projects (subdivisional and sub-item projects with relatively high safety risks) are high-risk areas and also the value highland of AI-empowered supervision [9].

5.1 Intelligent Monitoring of Deep Foundation Pit Engineering and Large-Scale Formwork Support System

Integrate the monitoring data of support structure displacement, settlement and internal force, the deformation data of surrounding buildings and pipelines, as well as groundwater and earth pressure data, and build an AI-based comprehensive safety evaluation and prediction model for foundation pits [10]. The model can not only evaluate the current safety status in real time, but also predict the deformation development trend in the future period based on time-series prediction algorithms (such as LSTM), realizing the real "predictive early warning". The system can simulate the safety response under different working conditions (such as continuous rainfall and surrounding loading), providing decision-making basis for dynamically adjusting the support scheme or emergency rescue.

Deploy wireless stress and inclination sensors and video monitoring on the key components of high formwork. The AI system analyzes the vertical pole axial force, horizontal displacement and other data in real time to judge whether there are signs of local overload and instability. Combined with 3D laser scanning or photogrammetry, the overall deformation field of the support system can be obtained regularly. Through the integration of finite element analysis and AI data-driven model, the overall stability of the system can be evaluated more accurately, providing full-process "supervision" during concrete pouring. As shown in Table 3.

Table 3. AI Early Warning Performance for Hazardous and Critical Projects

Monitoring scenario	Prediction Model	Early Warning Accuracy	False Alarm Rate
Deep foundation pit deformation	LSTM	92.3%	4.6%
High support instability	GRU+SVM	90.7%	5.3%
Slope landslide risk	Time-series analysis	91.5%	4.9%

5.2 Safety Control of Large Component Hoisting and Prefabricated Construction

For the hoisting of large steel structures and prefabricated components, BIM + UAV + AI vision can be used to preview the whole hoisting process in a virtual environment and optimize the selection of lifting points and hoisting paths. During actual hoisting, the state of the hoisted object is tracked in real time through UAVs or ground cameras, and the AI algorithm calculates its spatial relationship with the surrounding environment in real time to give millimeter-level early warning of possible collisions. In prefabricated construction, AI vision can accurately guide the positioning of prefabricated components and intelligently check the construction quality of connection nodes (such as the grouting fullness of sleeves).

5.3 Intelligent Emergency Command and Evacuation Simulation

Once a dangerous situation occurs in a hazardous and large-scale project, the AI system can quickly retrieve the real-time video, BIM model and personnel positioning information around the accident point, and recommend the best disposal plan in combination with the knowledge graph [11]. At the same time, based on the building information model and real-time personnel distribution, multi-path and dynamic emergency evacuation simulation is carried out by using AI algorithms to generate the optimal evacuation route and guide personnel to evacuate, minimizing losses.

6 Conclusion and Prospect

Despite the broad prospects, the comprehensive application of AI in construction engineering supervision still faces multiple challenges: at the technical level, the algorithm robustness and recognition accuracy in complex and unstructured construction site environments need to be improved; at the data level, there are "data islands", inconsistent data standards among various participants, and lack of high-quality annotated training data; at the standard and regulatory level, there are no national or industry standards for the processes, responsibilities and acceptance criteria of intelligent supervision, and the legal liability of AI decision-making is vague; at the talent and cost level, there is a shortage of compound talents, and the initial investment cost of small and medium-sized enterprises is relatively high[12].

Looking forward to the future, the intelligent development of construction engineering supervision will present the following trends: first, the deepening of human-machine collaboration. AI is not a replacement for supervisors, but a "super assistant" that handles repetitive, dangerous and massive data analysis work, allowing humans to focus more on complex decision-making, communication and coordination, and value judgment. Second, the evolution of autonomous intelligence. Moving from "perceptual intelligence" to "cognitive intelligence" and "decision-making intelligence", the system can not only "see" and "recognize", but also "understand" and "suggest", and even realize autonomous control in scenarios with clear rules. Third, platformization and ecologicalization. Cloud-based intelligent supervision SaaS services will lower the application threshold, form a unified digital base integrating BIM, IoT, AI and big data, and promote the collaboration of the industrial chain. Fourth, full-life-cycle expansion. Intelligent supervision will extend forward to the design and bidding stages, and backward to the operation and maintenance stage, realizing the digital and intelligent management of the whole life cycle of buildings.

The deep integration of artificial intelligence and construction engineering supervision is a profound industry transformation. Through the in-depth research on the four core application scenarios of BIM intelligent deepening, UAV intelligent inspection, AI active safety management and hazardous and large-scale project intelligent monitoring, this paper shows that AI technology can effectively break the bottlenecks of traditional supervision in information perception, analysis and judgment, risk pre-control and decision-making efficiency, and promote the transformation and upgrading of supervision work towards digitalization, automation and intelligence. These applications not only improve the quality and efficiency of supervision work, but also essentially strengthen the process control ability of engineering quality and safety.

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