Strategies for Effectively Enhancing Quality and Safety Supervision in Construction Projects: A Preliminary Study

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Abstract: The quality and safety of construction projects are not only related to the economic benefits of the projects but also affect the life and property safety of the people and the public interest of society. The accelerated advancement of new urbanization has led to construction projects characterized by larger scales, more complex technologies, and diversified formats. The traditional supervision and management model, which is dominated by administrative regulation and focuses on post-event punishment, can no longer meet the quality and safety requirements of engineering construction in the new era. Based on the current practical difficulties in quality and safety supervision and management of construction projects, this paper explores forward-looking and actionable enhancement strategies from the perspectives of conceptual innovation and technological empowerment, providing insights for constructing a modernized engineering quality and safety governance system.

1. Introduction

In the new stage of high-quality urban and rural development in China, construction projects have long surpassed the simple attribute of "building products" and have become important cornerstones bearing people's livelihood and well-being and demonstrating urban quality. The construction industry is undergoing profound changes, with prefabricated buildings, BIM technology, and new smart building technologies being widely applied. The scale of engineering construction continues to expand, and business forms continue to diversify. Simultaneously, quality and safety risks are becoming more concealed, spreading faster, and affecting broader areas. In the traditional supervision and management model, problems such as reliance on manual inspections, emphasis on post-event accountability, and insufficient inter-departmental collaboration are becoming increasingly prominent. Some projects, due to inadequate supervision, exhibit structural risks and functional defects, causing not only economic losses but also damaging the industry's reputation. Against this background, re-examining the core logic of quality and safety supervision and management for construction projects and exploring new strategies that meet the development needs of the new era have become inevitable choices for addressing industry pain points.

2. Practical Difficulties and Era Requirements for Quality and Safety Supervision in Construction Engineering

2.1 Prominent Contradictions in the Current Supervision Model

The limitations of the traditional model are mainly manifested in three aspects of "imbalance": Firstly, the imbalance between supervisory resources and supervisory demands. The construction market continues to expand, but the supervision efforts of housing and urban-rural development departments across various regions have not been correspondingly strengthened. Supervisory personnel are in a state of "passive response," making it difficult to conduct high-frequency and in-depth inspections of high-risk projects and key links, resulting in superficial supervision. Secondly, the imbalance between post-event punishment and pre-event prevention. Current

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supervision mainly focuses on "problem investigation and handling." Taking disciplinary measures after identifying hidden dangers through inspections, while capable of deterring violations, can hardly avoid potential risks at the source. Some projects, due to supervisory neglect in critical early stages, lead to quality and safety issues, ultimately causing loss of life and property and negative public opinion [1]. Furthermore, the imbalance between primary responsibility and supervisory responsibility. Construction, engineering, and supervision companies are originally the main entities responsible for quality and safety. However, some regulatory authorities take over everything, excessively interfering with the daily management of enterprises, thereby weakening their sense of responsibility. Some construction units treat quality and safety management as a "perfunctory task," temporarily supplementing materials before inspections and doing superficial work, only to revert to extensive construction after inspections, forming a "supervision dependence syndrome" and falling into a vicious cycle of "stricter supervision, more passive enterprises."

2.2 Core Requirements for Engineering Quality and Safety in the New Era

With the continuous advancement of new construction industrialization and intelligent construction, quality and safety supervision and management in construction engineering need to achieve three "shifts": First, the focus of supervision should shift from "compliance supervision" to "value supervision." Regulatory bodies must break through traditional baseline requirements and, while ensuring basic conditions such as structural safety and compliance with fire regulations, further emphasize the project's durability, functionality, and green performance, ultimately achieving the unity of "baseline protection" and "value addition" [2]. Second, supervisory means should shift from "human-led" to "intelligent collaboration." Faced with the increased concealment of hidden dangers and enhanced risk correlation brought by new technology applications, regulatory authorities need to break away from the traditional model reliant on human experience, proactively use digital tools for accurate identification and early warning of engineering quality and safety risks, and improve the precision and efficiency of supervision. Third, the supervisory pattern should shift from "single supervision" to "multi-party co-governance." Government regulatory departments must break the traditional pattern of government monopoly, clarify the boundaries of rights and responsibilities of various participants such as construction units, and supervision units through systems, and simultaneously smooth the supervision channels for third parties such as the public and industry associations, building a quality and safety management synergy system of "government leadership, enterprise responsibility, and social participation."

3. Conceptual Innovation: Reconstructing Supervision Logic with Risk Governance at the Core

Improving the efficiency of quality and safety supervision and management in construction projects first requires conceptual innovation. The "risk governance" concept requires regulatory authorities to focus on "risk prediction," identify potential hazards in advance, scientifically assess risk levels, and take timely prevention and control measures to prevent quality and safety issues before they occur.

In establishing a full-cycle risk identification mechanism, the quality and safety risks of construction projects run through the entire cycle from survey and design to construction and completion acceptance, with risk points at different stages having differentiated characteristics. Traditional supervision mostly focuses on the construction stage, while full-cycle risk identification requires regulatory authorities to achieve "stage coverage with emphasis on key points." During the survey and design stage, regulatory authorities should guide relevant units to focus on identifying "source risks": survey units should conduct accurate surveys of geological conditions and the surrounding environment to avoid unreasonable design schemes due to distorted survey data [3]. Design units need to strengthen "safety redundancy design"; for example, for building structures in earthquake-prone areas, the seismic fortification level should be increased beyond the standard requirements. Meanwhile, supervision departments can introduce a "third-party review mechanism for survey and design documents," entrusting professional institutions to independently evaluate the completeness of survey reports and the safety of design schemes, and using the evaluation results as a prerequisite for project commencement permits [4].

Upon entering the construction stage, regulatory authorities need to urge all parties to focus on identifying "process risks." As the construction stage is a high-incidence period for quality and safety hidden dangers, regulatory authorities can require construction units to establish "risk lists" for key processes and high-risk operation links. For example, during deep excavation, attention should be paid to slope stability and dewatering effects. For it is necessary to inspect the erection of scaffolding and the safety devices of lifting machinery. For prefabricated construction, the grouting fullness of component connection nodes should be verified. Additionally, supervision departments can require construction units to submit a "Risk Investigation Record Form" daily, implementing full-process supervision of high-risk processes such as "pre-construction reporting, on-site supervision during construction, and post-construction acceptance."

During the completion acceptance stage, regulatory authorities need to urge all parties to focus on identifying "functional risks." Completion acceptance not only needs to verify whether the project meets structural safety standards but also pay attention to the compliance of usage functions. For example, for residential projects, indoor air quality, sealing performance of water supply and drainage pipelines, and insulation of electrical circuits need to be tested. Public buildings require verification of the interlocking function of fire protection systems and the operational stability of elevators. Regulatory authorities can introduce "user experience acceptance," inviting some owner representatives to participate in the acceptance process, evaluate indicators related to living experience such as door and window sealing and wall flatness, and incorporate the evaluation results into the individual acceptance records of project quality.

4. Technological Empowerment: Enhancing Supervision Efficiency Supported by "Digital Intelligence"

To break through the bottleneck of supervisory resources and achieve precise supervision of construction project quality and safety, technological innovation is the key path. The application of big data, the Internet of Things (IoT), and artificial intelligence (AI) technologies in the engineering construction field is becoming increasingly widespread. Regulatory authorities are promoting the transformation of construction engineering quality and safety supervision and management from labor-intensive to technology-intensive.

4.1 Building a Full-Element IoT Perception System

In building a full-element IoT perception system, the IoT perception system led by regulatory authorities will guide construction units to deploy various sensors on the project site to achieve dynamic perception of elements such as structural stress, environmental changes, and construction behaviors, providing data support for risk early warning [5]. Specifically, the construction of the perception network can be advanced in three aspects: First, regulatory authorities require construction units to install sensors at key parts of the building structure to monitor the stress state and deformation of the structure in real time. For example, installing stress sensors on the core tubes and frame beams of high-rise buildings to monitor whether the stress on the concrete structure is within the design allowable range; installing displacement sensors on the slopes and support piles of deep foundations to collect data on slope settlement and pile inclination in real time. When displacement exceeds the early warning threshold, the system automatically sends warning information to supervisors and construction units. Second, for risk factors such as dust, noise, and geological hazards on the construction site, regulatory authorities urge construction units to configure corresponding perception devices. Dust sensors can be installed at the entrances and exits of construction sites to monitor the concentration of PM2.5 and PM10 in real time. When the concentration exceeds the standard, fog cannons automatically start to reduce dust. Geological disaster monitoring instruments are installed at mountain project sites to monitor precursors of landslides and mudslides (such as soil moisture content, mountain displacement rate, etc.), buying time for the evacuation of construction personnel. In 2023, a construction unit for a mountain highway project detected landslide risks three hours in advance through an environmental risk perception system, enabling the safe evacuation of over 200 construction workers and avoiding a large-scale casualty accident. Third, regulatory authorities encourage construction units to use video surveillance and AI recognition technology to monitor construction workers' violations in real time. Construction units will install smart cameras in key areas of the construction site, use computer vision technology to identify behaviors such as "not wearing safety helmets, not fastening safety belts during, and immediately issue warnings via on-site broadcasting after identification, and push violation information to the mobile phones of construction unit management personnel to urge on-site rectification [6].

4.2 Building a Big Data-Driven Supervision Platform

This platform, with "data aggregation - intelligent analysis - result application" as its core functions, promotes the shift of supervision from "experience judgment" to "data-driven decision-making." Its architectural design includes three core modules: First, the data aggregation module. Regulatory authorities integrate data from multiple units, establish unified standards (covering data categories such as enterprise qualifications, engineering technology, on-site monitoring, and hidden danger disposal), and achieve "real-time uploading and automatic verification" of data through standardized interfaces to ensure data completeness and accuracy [7]. Second, the intelligent analysis module. Regulatory authorities use big data algorithms to analyze data, mine patterns and trends of hidden dangers, clarify key supervision links, evaluate the management level of units through enterprise profiles, and provide a basis for differentiated supervision. Third, the result application module: Regulatory authorities visually present analysis results to assist in formulating supervision strategies, while opening to guide the public in choosing compliant entities, forming a "market forcing" mechanism.

4.3 Application of Artificial Intelligence Technology

Currently, the application of AI in supervision and management by regulatory authorities mainly focuses on two directions: First, AI-assisted hidden danger identification. Traditional hidden danger identification relies on the professional experience of supervisors and is susceptible to subjective factors. Regulatory authorities will guide technical teams to use AI technology to achieve automatic identification of hidden dangers through image recognition and data comparison. For example, by comparing the BIM model of construction drawings with 3D scan data of on-site construction, AI can automatically identify quality issues such as "reinforcement spacing deviation, component position offset." By analyzing on-site video footage, AI can identify safety hazards such as "excessive spacing of template support uprights, lack of edge protection," and mark the location, type, and severity of the hidden danger for supervisors to verify [8]. Second, AI risk prediction and early warning. Regulatory authorities entrust technical institutions to develop AI models based on historical data and real-time monitoring data to predict engineering quality and safety risks and avoid potential accidents in advance. For example, by training a "deep foundation pit collapse risk prediction model," inputting parameters such as geological conditions, support methods, and dewatering data, the model can predict the probability of collapse risk in the next 7 days. When the probability exceeds 80%, it sends a high-level warning to the regulatory authorities. By training a "concrete strength development prediction model," inputting data such as mix ratio, curing temperature, and curing time, the model can predict the 28-day strength of concrete. If the predicted value is lower than the design strength, the regulatory authorities can require the construction unit to adjust the curing plan in advance. The application of AI prediction and early warning technology shifts supervision from "passive response" to "active prevention," significantly reducing the probability of quality and safety accidents. The application of AI technology can further enhance the precision and efficiency of regulatory authorities' decision-making, especially in the fields of hidden danger identification and risk prediction.

5. Conclusion

Enhancing the quality and safety supervision and management of construction projects is a long-term and arduous task. It requires breaking away from the path dependence of traditional models, guiding the direction with conceptual innovation, and enhancing efficiency with technological empowerment. With the further development of intelligent construction technologies (such as the popularization of construction robots and digital twins), supervision and management will deepen towards "unmanned and intelligent" directions. Simultaneously, the improvement of the social governance system and public participation in engineering quality and safety will continue to increase, ultimately forming a benign ecology of "government supervision with strength, enterprise self-control with depth, and social supervision with breadth," providing a solid guarantee for the quality and safety of construction projects.

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