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

Since the new stage of high-quality urban and rural development in China, construction projects have long been more than "building products", but also play an important role as the foundation for people's better livelihood quality and urban quality. Such as prefabricated buildings, BIM technology and new smart building technologies are widely used in construction industry; The scale of construction engineering continues to expand, and business forms continue to diversify. At the same time, risks associated with quality and safety become less visible, accelerate their dissemination across larger areas. At present, the traditional supervision and management model such as relying on manual inspection, focusing on responsibility after event occurrence, poor coordination between departments and other issues are increasingly prominent. With many projects lacking effective supervision, this situation has resulted in structural risks and functional defects for some projects, leading to economic losses from shallow resources at best and an undermining of the reputation of the industry at worst. In this context, rethinking quality safety supervision management for construction projects core logic and how to explore the new strategies in line with the development needs of the new era has become an inevitable choice to solve 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 primarily reflected in three aspects of "imbalance". First, the imbalance between supervisory resources and supervisory needs. The construction market is still growing, but the supervision of housing and urban-rural development departments in various places has not been strengthened accordingly. Some supervisory personnel are in a passive response state, limiting their ability to carry out high-frequency and deep inspections on major projects and key links, which leads to relatively superficial supervision. Second, the differential punishment after event vs prevention before event. Presently, the supervision is rather "problem investigation and handling". Although the inspections can identify hidden dangers, the implementation of disciplinary

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measures after discovering these risks may only deter violations but hardly prevent from accident occurrence at its source. Certain projects do not meet quality and safety standards because supervision was neglected in important early stages, leading to loss of life and property from preventable damage, and damaging public attitudes towards the industry [1]. Also, the slack between operational responsibility and supervisory responsibility. Originally, construction (engineering and supervision) companies are the main responsible organization for quality and safety. Yet, there are some regulators that take over everything, excessively meddling with the everyday operational decisions to such an extent that they dilute the accountability of companies. But there are also some construction units, in the quality and safety management, treat it as a "perfunctory task", to be inspected before using materials temporarily supplements after inspection and shallow work, the post-inspection extensive construction formation "supervision dependence syndrome", down into the "more strict supervision; passive enterprise" vicious circle.

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

In addition, in the context of new construction industrialization and intelligent construction technology are advancing carefully, the supervision and management of construction engineering quality and safety should achieve three "shifts": First, the shift from "compliance supervision" to "value supervision." Regulatory bodies should move away from traditional baseline requirements and, although taking structural safety and fire regulations into account, stress the endurance of the project in terms of performance and greenness so that "baseline protection" can coalesce with "value addition" [2]. Second: supervisory, from "human-led" to "intelligent collaboration." The new era of technology applications, the concealment of hidden dangers is more serious, and the risk correlation is getting stronger, regulatory authorities should abandon the traditional reliance on human experience model and take initiative to use digital tools to accurately identify engineering quality safety risks and give early warning, so as to improve supervision accuracy and efficiency. Third, the supervision pattern should change from single supervision to multi-party co-governance. Government regulatory departments must break the traditional governance model of government monopoly, increase institutional clarity on the boundaries of rights and responsibilities for multiple participants (such as construction units, supervision units), at the same time unblocking third-party oversight channels (including public review channels, industry association reviews) to form a quality and safety management synergistic system with "government leadership, enterprise responsibility, social protection".

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

Conceptual innovation is the priority to improve the efficiency of quality and safety supervision and management in construction projects. Development stage The concept of risk governance requires regulatory authorities to implement "risk prediction," pre-clear potential hazards, conduct sound risk assessment to determine the level of risk, and take preventive and control measures accordingly so that quality and safety issues can be controlled before they occur.

Through the construction survey and design, construction, and completion acceptance are reiterated that the whole cycle of planning to building delivery process indicates obvious risks throughout the main characteristics it involves. Traditional supervision has mainly been centered on the construction stage, while full-cycle risk identification needs regulators to have "stage-wide coverage and key-point emphasis." In the survey and design stage, guidance by regulatory authorities should lead relevant units to focus on controlling "source risks": survey units need to carry out objective surveys of geological conditions and surrounding environment in order to counteract non-rational designs as a result of distorted surveys [3]. Design units must more prudently strengthen "safety redundancy design"; such as the seismic fortification level behind buildings for earthquake-prone areas should be higher than that of standard. In contrast, supervision departments can establish a "third-party review mechanism for survey and design documents," outsourcing professional institutions to expert evaluate the completeness of survey reports and safety of design

schemes, with evaluation results serving as project commencement permit prerequisites [4].

When it gets to the stage of construction, regulating authorities must prompt all stakeholders to concentrate on recognizing "control dangers." Because the construction stage is a high-incidence period of various quality and safety hidden dangers, regulatory authorities can require construction units to form "risk lists" for key processes and high-risk operation links. Deep excavation, slope stability and dewatering effects are just some examples to consider. Because there is a need to examine scaffolding structure and lift machinery safety devices. The conditions of supply control used are as follows: For prefabricated construction, the grouting fullness of component connection nodes should be verified. The supervision departments can also require construction units to submit a "daily risk investigation record form" to achieve full-process supervision of high-risk processes such as "pre-construction report, on-site supervision during construction and post-construction acceptance".

It is important for regulators to call upon all relevant parties, during the completion acceptance phase, to prioritize on finding "functional risks". The acceptation of the completion not only needs to check if it meets the structural safety requirements, but also pay attention to the compliance with usage functions. In residential projects, for example: the need to test indoor air quality, water supply and drainage pipeline seal performance test, electrical circuit insulation testing. They need to confirm the interlocking function of fire protection systems (such as smoke control & fire alarm systems) and that elevators operate normally. Regulatory authorities may formulate "user experience acceptance" to allow part of the owner representative to participate in the acceptance process, evaluate the indicators affecting the living experience (such as sealing of doors and windows, flatness of boundary wall), and incorporate into each unit's quality individual account.

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

Technological innovation is the key path to solve the bottleneck of supervisory resources and realize refined supervision for construction project quality, safety and work. Introduction of big data, the Internet of Things (IoT) and artificial intelligence (AI) technologies have been widely used in engineering construction. Promoting the shift from labor-intensive to technology-intensive of construction engineering quality and safety supervision and management is advocated by regulatory authorities.

4.1 Building a Full-Element IoT Perception System

To construct the whole-element IoT perception system, the IoT perception system directed by regulatory authorities will guide construction units to equip with various sensors on project site so that dynamic awareness of structural stress, environmental change, and construction behavior can be realized to provide data support for risk early warning [5]. In particular, there are still three approaches that can be adopted to progressively improve the construction of the perception network: regulatory authorities require the construction unit to install at certain key parts around the mesoscopic structure with several sensors, which help continuously monitor in-situ stress state and deformation of structure body. That is, to install stress sensors on the core tubes and frame beams of high-rise buildings to monitor whether the stress condition of the concrete structure meets the design allowable range; Install displacement sensors on slopes and support piles of deep foundations for real-time collection of slope settlement data and pile inclination. Displacement records exceeding the early warning threshold will be sent automatically, by the system itself. The information is directed to supervisors and construction units. Secondly, regulatory authorities encourage construction units to equip relevant perception devices for risk factors like dust, noise and geological hazards present on the site for merits. You can install dust sensors at the entrance and exit points of construction sites to determine the concentration of PM2.5 and PM10 in real time. If the concentration exceeds the standard, fog cannons automatically work to suppress the dust. At the mountain project sites, geological disaster monitoring instruments (such as soil moisture content, mountain displacement rate, etc.) are installed to monitor precursors of landslides and mudslides to

provide time for the evacuation of construction personnel. In 2023, the construction unit for a mountain highway project recognised the risk of landslides three hours in advance through an environmental risk perception system, successfully evacuating over 200 construction personnel and avoiding what could have been a large-scale casualty accident. Third, regulatory authorities promote that construction units use video surveillance and AI recognition technology to monitor construction site violations of workers in real time. The Construction Units install the smart cameras in key locations of the construction site, and when identifying behavior such as "not wearing a safety helmet", "during not fastening safety belts" and other behaviors through computer vision technology, they are directly identified In this way, immediate warnings will be issued on-site through broadcasting after identification, and violation information will be pushed to the mobile phones of construction unit management personnel on site for timely rectification [6].

4.2 Building a Big Data-Driven Supervision Platform

The general construction of this platform, which has "data aggregation - intelligent analysis - result application" as its three main functions, guides the transformation of supervision from "experience judgment" to "data-driven decision-making". Architecturally, it consists of 3 main modules: The data aggregation module first. Regulatory authorities combined data from multiple units, set unified norms (including enterprise qualifications, engineering technology, on-site monitoring and hidden danger disposal) and through standardized interfaces realized the full configuration of real-time uploading and automatic verification of various data to ensure the completeness and authenticity of all kinds of data [7]. Second, the intelligent analysis module. By way of data analysis using big data algorithms, the regulatory authority mines patterns and trends in hidden dangers and clarifies key field supervision links. Profiles can be used to comprehensively evaluate the management level inside units-giving a basis for differentiated supervision. Third, the effect application module: The regulatory authorities visually present analysis results to guide the development of supervision strategies and open to guide consumers in choosing compliant entities, forming a "market forcing" mechanism.

4.3 Application of Artificial Intelligence Technology

At present, the use of AI technology in regulatory authorities for supervision and management mainly has two directions. One is based on AI-assistant hidden danger identification. Traditional hidden danger identification depends heavily on the supervisors on-site professional experience and is subject to more subjective factors. Regulatory authorities will guide the technical team to organically combine AI technology with automatic identification of hidden danger in image recognition and data comparison. AI, for instance, can compare the BIM model of construction drawings with 3D scan data on site by saying its "reinforcement spacing deviation, component position offset." AI, via the analysis of on-site video footage, can also identify safety hazards in situ (excessive spacing between template support uprights, lack of edge protection) and tag the hidden danger with location, type and scale (similar efforts in identifying distracted walking behaviors could easily be repurposed to identify quality control violations) [8]. Secondly, prediction and early warning of the risk of AI. Regulatory authorities have to rely on functional technical institutes which they invest in and trust to build AI models from historical data, and real-time monitoring data that can help avoid accidents into the future. Such as input parameters such as geological conditions, support measures and dewatering data will feed into the train model called "deep foundation pit collapse risk prediction model" to predict the probability of collapse risk in the next 7 days. If the probability is greater than 80% then it will trigger a high level alert to the regulators. Concrete strength development prediction model can be built by establishing a generalization between parameters like mix ratio, temperature and curing time of concrete and the 28-day strength of concrete. When the predictive value is apparently lower than the design strength, the regulatory department may require construction unit to change curing program previous. By using AI prediction and early warning technology, the application of non-vision quality and safety supervision shifts from "passive response" to "active prevention," which greatly reduces the probability of quality and safety accidents. AI technology could make the decision-making of

relevant regulatory authorities more accurate in hidden danger identification and risk prediction, especially applied to various types of reports.

5. Conclusion

Quality and Safety Supervision and Management of Construction projects is a long-term and arduous task. This needs to break out of the value stagnation of the traditional model, leading with establishment innovation for direction and technology empowerment for efficiency; As intelligent construction technologies continue to advance (e.g., the widespread application of construction robots and digital twins), supervision and management will further deepen into "unmanned + intelligence" direction. At the same time, social governance system improvement and public participation in engineering quality and safety will continue to deep into all aspects of each link, ultimately forming a "government supervision with strength + enterprise self-control with depth + social supervision with breadth" good ecology for effective protection for construction project quality and safety.

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