Analysis of Quality and Safety Management Paths for Housing Construction Engineering from the Perspective of Smart Construction Sites

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Abstract: Against the backdrop of digital transformation in the construction industry, the concept of smart construction sites is being widely adopted. As modern housing construction projects become increasingly complex, leveraging the advantages of smart construction sites to enhance the quality of housing construction engineering has become a key focus within the entire industry. This paper briefly outlines the concept of smart construction sites, expounds on the importance and main modules of strengthening quality and safety management in housing construction engineering from this perspective, and proposes scientific and rational management paths. These include comprehensive digital integrated management of all elements, innovating intelligent equipment and processes, establishing risk early warning and dynamic response mechanisms, building a whole-process quality traceability system, and implementing collaborative supervision. The aim is to provide reference suggestions for the high-quality development of housing construction engineering.

1. Introduction

Housing construction is the foundation of urban development, with its scale and quantity gradually increasing. The quality and safety of housing construction directly relate to the life and property safety of the public and are fundamental guarantees for harmonious social development. With the progression of time, traditional quality and safety management models in housing construction engineering have begun to reveal limitations. The concept of smart construction sites has emerged, utilizing technologies such as the Internet of Things (IoT), big data, and cloud computing to enable real-time perception of elements like equipment, materials, and personnel at the construction site. This helps managers accurately grasp project progress and quality and safety conditions. Therefore, deeply exploring the paths for quality and safety management in housing construction engineering from the perspective of smart construction sites is an important measure for the intelligent development of the construction industry.

2. Overview of Smart Construction Sites

Smart construction sites are a significant product of the deep integration of advanced technologies like big data, artificial intelligence, and the Internet of Things with traditional construction, symbolizing the industry's move towards intelligence and modernization. Smart construction sites utilize various sensors and intelligent devices to accurately track the activity trajectories and locations of construction personnel, providing comprehensive protection for construction safety. They also enable the collection of data on temperature, humidity, dust concentration, and other environmental parameters through deployed monitoring equipment, allowing construction managers to take measures such as dust suppression and cooling based on actual site conditions, thereby significantly improving the construction site environment. Cloud computing and big data analysis technologies within the smart construction site framework allow

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for in-depth exploration and analysis of massive data sets. Managers can supervise construction progress and quality through mobile terminal management platforms, achieving efficient collaborative management. Furthermore, smart construction sites are a core driver for the green development of the construction industry. Housing construction engineering, aided by intelligent energy management systems, can optimize equipment operation, minimize energy consumption generated during construction, and improve the recycling rate of construction waste through classification systems, providing strong support for efficient construction and sustainable development.

3. Importance of Strengthening Quality and Safety Management in Housing Construction Engineering from the Perspective of Smart Construction Sites

3.1 Ensuring the Life and Property Safety of the People

Quality and safety are core elements of housing construction projects and fundamental conditions for ensuring the life and property safety of the people [1]. Quality and safety management in housing construction under smart construction sites can utilize big data and IoT technologies to monitor data from various construction stages. Upon detecting abnormal information, the system automatically issues warnings, allowing potential safety hazards to be promptly addressed, thereby eliminating safety risks at their root. Simultaneously, quality and safety management in housing construction, supported by smart construction sites, can precisely control quality, ensuring every construction process meets standard specifications, reducing later maintenance costs, and safeguarding the interests of construction units and owners. Quality and safety management in housing construction under the smart construction site paradigm, bolstered by technology, becomes a solid backing for ensuring public life and property and an indispensable condition for promoting the stable development of the construction industry.

3.2 Promoting the Healthy Development of the Construction Industry

Quality and safety management in housing construction engineering under smart construction sites is key to promoting the stable development of the entire construction industry. From a quality assurance perspective, the housing construction engineering management model under smart construction sites ensures that every brick and every steel bar meets quality standards. Supported by data analysis, it helps construction enterprises promptly identify and optimize process issues, ensuring the overall quality and construction level of housing buildings. Furthermore, adhering to the concept of smart construction sites in quality and safety management allows for the timely phasing out of outdated production capacity and non-compliant enterprises, enabling resources to be centrally integrated towards higher quality, providing a fundamental guarantee for the standardized and intelligent development of the construction industry.

4. Main Modules of Quality and Safety Management in Housing Construction Engineering from the Perspective of Smart Construction Sites

4.1 Comprehensive Resource Collaborative Management Module

Quality and safety management in housing construction engineering from the perspective of smart construction sites integrates IoT, big data, and BIM technologies through comprehensive resource collaborative management. This management model advocates for data-driven decision-making as its core, utilizing smart safety helmets and environmental monitoring equipment to collect construction data in real-time and upload it to a cloud platform for dynamic analysis.

Additionally, the comprehensive resource collaborative management module can use functions like facial recognition and safety helmet positioning to record attendance, linking the results with salary distribution mechanisms to avoid future economic disputes. Moreover, the risk graded management and control mechanism within this module can promptly investigate potential safety hazards, intelligently identify violations and dangerous behaviors on site, thereby establishing a multi-element collaborative optimization relationship between construction quality, safety, and progress, significantly improving the rectification rate of safety hazards.

4.2 Multi-dimensional Data Decision Support Module

Quality and safety management in housing construction engineering under smart construction sites relies on a multi-dimensional data decision support module to enhance the level of refinement of management. This module integrates technologies like IoT and big data analysis to collect data on various elements of the construction site, establishing a data pool covering information on construction progress, safety inspections, and more. At the same time, construction enterprises use machine learning algorithms to deeply mine historical data, automatically generating heat maps of quality and safety hazards, providing managers with visual decision-making references. The application of the multi-dimensional data decision support module facilitates a shift in housing construction quality and safety control from passive handling to active prevention, significantly improving the first-time acceptance pass rate and providing reliable data-driven support for smart construction site development.

4.3 Intelligent Safety Risk Early Warning Module

Quality and safety management in housing construction engineering, aided by the concept of smart construction sites, can smoothly achieve intelligent development. Among these, the intelligent risk early warning module deeply integrates IoT and AI technologies, deploying high-precision sensors in various areas of the site [2]. Supported by big data analysis algorithms, construction enterprises can deeply mine massive information data, accurately identify risk patterns and development trends. Upon detecting risk signals, they can be promptly pushed to managers, helping housing construction engineering managers develop risk response strategies quickly, reducing the probability of safety accidents, and providing an intelligent safety defense line for housing construction quality and safety.

5. Quality and Safety Management Paths for Housing Construction Engineering from the Perspective of Smart Construction Sites

5.1 Implementing Comprehensive Digital Integrated Management of All Elements

Quality and safety management in housing construction engineering from the perspective of smart construction sites should focus on data-driven comprehensive digital integrated management of all elements, establishing a dynamic collaborative system encompassing construction personnel, equipment, and methods. Construction enterprises should adopt BIM and GIS technologies to create digital mappings of the engineering entity and the construction environment, integrate and analyze data from geological surveys, design drawings, construction simulations, etc., forming a dynamically updated 3D visual model. On this basis, enterprises should also develop a smart construction site middle-platform system integrating quality, safety, progress, cost, and other modules, achieving data interoperability and business linkage between elements. Using RFID chips, trace the entire lifecycle of materials like steel and concrete, and combine with blockchain technology to ensure the immutability of test reports. This process should integrate historical

engineering data and real-time monitoring information to build a machine learning-based quality and safety risk prediction system. For key processes like concrete pouring and deep foundation excavation, establish an assessment matrix containing over 200 risk factors, and calculate accident probability through Monte Carlo simulation. Furthermore, quality and safety management should utilize big data and AI algorithms to perform cross-analysis and deep mining of the integrated massive data, build quality and safety risk early warning models to assess risk situations, automatically push warning information to relevant responsible persons, and enhance management efficiency and response speed. On this basis, use digital collaboration platforms to achieve transparency, sharing, and online collaboration of quality and safety data processes. Decision-makers can globally grasp the project situation, while the project level is responsible for executing tasks, forming a new ecology where all personnel actively participate in quality and safety management.

5.2 Innovating Intelligent Equipment and Processes

Quality and safety management in housing construction engineering from the perspective of smart construction sites should treat technological innovation as the main driving force, building a smart management and control system integrating equipment, processes, and management. In terms of equipment, deploy composite smart terminals, embed multi-modal sensors in large equipment like tower cranes and construction elevators to collect operational status, load data, and environmental parameters in real-time, achieving millisecond-level response for anomaly warnings through edge computing. At the same time, construction enterprises should combine UWB high-precision positioning systems to create dynamic profiles of personnel, actively intervening in risky behaviors [3]. On this basis, housing construction enterprises should promote intelligent production lines for prefabricated buildings, integrate technologies like machine vision and flexible grasping to automatically control component production processes, controlling errors within ±0.5mm. They can also use AI analysis technology to real-time check key protective measures like edge protection and opening covers, automatically generate rectification work orders) and push them to responsible persons. Innovation lies not only in hardware but also in the reengineering of process management workflows. The core of process management reengineering is promoting the dynamic integration of BIM technology with the construction process, associating data collected by IoT with the BIM model to achieve visual collaborative management of information such as construction progress, quality acceptance, and safety hazard handling, enabling final management decisions to be evidence-based and driving housing construction engineering towards the modern goals of zero accidents, zero defects, and high efficiency.

5.3 Establishing Risk Early Warning and Dynamic Response Mechanisms

Quality and safety management in housing construction engineering from the perspective of smart construction sites must build risk early warning and dynamic response mechanisms, deeply integrating technologies like IoT, big data, and AI to carry out risk identification, assessment, early warning, and handling. Construction enterprises should deploy intelligent sensors, drones, and other equipment to collect data on structural stress, settlement displacement, environmental temperature, and humidity in real-time. Referring to the BIM model and construction progress information, establish a full-element digital foundation. Use edge computing nodes to clean and preprocess raw data, ensuring data timeliness and accuracy, providing basic support for risk analysis. The system can automatically trigger emergency plans and assign handling tasks upon issuing a warning. Site managers, upon receiving instructions on their mobile terminals, can accurately and quickly locate hidden danger points and handle them. All warning events and handling records are archived by the

system, forming a traceable knowledge base. At the same time, construction enterprises should closely integrate with the concept of smart construction sites, build an intelligent early warning analysis center, transmit collected data to the cloud-based smart management platform, use big data analysis and AI algorithms for deep mining, and comprehensively enhance the quality and safety level of housing construction engineering by regularly analyzing and reviewing early warning data.

5.4 Implementing Collaborative Supervision

Quality and safety management in housing construction engineering from the perspective of smart construction sites should actively carry out collaborative supervision. By unifying data interface standards, ensure real-time data sharing among multiple entities such as housing construction departments, construction units, and supervision parties. In the collaborative supervision phase, construction enterprises should also use big data analysis technology to efficiently integrate information such as historical accident data and on-site inspection records, establish a dynamic assessment system for quality and safety risks, and coordinate with the introduction of blockchain technology to ensure the immutability of key node data, providing a credible basis for quality traceability and responsibility determination in housing construction engineering [4].At the same time, construction enterprises should build a collaborative governance mechanism led by the government with the participation of third-party institutions, linking quality and safety performance with credit evaluation and bidding. In addition, quality and safety management in collaborative supervision should integrate cloud computing, IoT, and BIM technologies to build a unified smart construction site collaborative management cloud platform. Integrate data from various subsystems such as quality inspection, safety monitoring, and personnel management for in-depth analysis, ensuring that design, construction, supervision, and regulatory units share data through a unified portal. The construction of the collaborative management platform should introduce standardized quality and safety control processes, clarify the primary responsibility of the construction unit, and adopt processes such as online task assignment, closed-loop management of hidden danger rectification, and electronic signing to leverage the advantages of collaborative supervision. Housing construction engineering managers should record quality and safety data based on the collaborative platform, establish digital credit files, link these files with the credit system of the industry regulatory authority, incentivize all parties to actively participate in collaborative management, and form a positive collaborative mechanism in the field of housing construction quality and safety management.

6. Conclusion

In summary, quality and safety management in housing construction engineering is transitioning towards digitalization and intelligence. The emergence of smart construction sites has improved the refinement level of engineering project management and, aided by data-driven decision-making mechanisms, formed a new model for quality and safety management. Therefore, construction enterprises should proceed from the perspective of smart construction sites, implement comprehensive digital integrated management of all elements, innovate intelligent equipment and processes, establish engineering risk early warning and dynamic response mechanisms, and implement collaborative supervision during housing construction quality and safety management, providing a fundamental guarantee for the high-quality development of housing construction engineering.

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