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Technological Innovation and Risk Prevention and Control in Real Estate Project Management: Practical Exploration of Prefabricated Buildings

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Abstract: This article explores the technological innovation and risk control of prefabricated buildings in real estate projects, pointing out that although prefabricated buildings have advantages, they also carry risks. It introduces the core technologies, elaborates on the implementation paths of technological innovation from multiple aspects, constructs a risk system, analyzes the characteristics of industry risks, and verifies through cases. It proposes that development should focus on three aspects: technology standardization, intelligent risk systems, and stakeholder collaboration. In the future, research can be conducted on AI risk prediction and the application of circular economy.

Keywords: Prefabricated buildings; Technological innovation; Risk prevention and control

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1. Introduction

In the contemporary construction industry, technological innovation, especially prefabricated building technology, is revolutionizing real estate project management. For instance, the development of a blockchain-enabled IoT-integrated construction platform exemplifies how digital technologies can enhance the management and execution of prefabricated housing projects [1]. However, such innovation also introduces new risks that require careful management. To support the development of this technology, governments worldwide have issued relevant policies to promote the application of prefabricated building technology in real estate projects, aiming to achieve energy-saving, environmental-friendly, and high-quality construction goals. This paper explores the practical aspects of prefabricated building technological innovation in real estate project management, focusing on risk prevention and control. By analyzing cases, identifying risks, and proposing countermeasures, it provides valuable insights for industry practitioners to better utilize this technology while managing associated risks, thus promoting the healthy development of the prefabricated building industry in the real estate sector.

1.1. Technological innovation in prefabricated building systems

1.1.1. Core technical components of modular construction

The modular construction in prefabricated building systems encompasses several core technical components. The structural design systems play a fundamental role. They are designed to ensure the overall stability and load-bearing capacity of the modular units. Modular structures need to be carefully engineered, taking into account factors such as wind resistance, seismic performance, and the distribution of weight within each module. For example, the connection points between modules are crucial elements in the structural design, which must be strong enough to withstand various forces during transportation, installation, and the building's service life [2].

Standardized component production techniques are another key aspect. In modular construction, components are manufactured in a factory-controlled environment. This standardization ensures high-quality production, reduces waste, and speeds up the construction process. Precise manufacturing processes, such as using computer-controlled machinery for cutting, shaping, and assembling components, guarantee that each module is consistent in size and quality. This not only simplifies the installation but also allows for easy replacement of components if necessary.

The intelligent installation processes are integral to modular construction. With the help of modern technologies like GPS-guided cranes and robotic assembly systems, modules can be installed with greater accuracy and efficiency. These intelligent systems can monitor and adjust the installation process in real-time, minimizing human error and ensuring that the modules are correctly positioned. Additionally, they can improve site safety by reducing the need for manual labor in potentially dangerous installation tasks.

1.1.2. Implementation pathways in real estate development

In real estate development, promoting technological innovation in prefabricated building systems requires a multi-faceted approach as outlined.

(1) Developers should collaborate closely with research institutions and technology providers. For example, they can jointly develop new prefabricated building materials with better thermal insulation, soundproofing, and durability properties. This not only improves the quality of the final real-estate product but also enhances its market competitiveness;

(2) The integration of digital technologies is crucial. By adopting BIM, real-time monitoring systems, and intelligent manufacturing in the prefabrication process, the entire production and construction can be optimized. BIM, for instance, enables accurate visualization of the prefabricated building components, facilitating seamless assembly on-site [3];

(3) The construction process needs to be re-engineered. Traditional construction workflows often have inefficiencies that can be overcome with prefabricated building systems. Developers should design a more streamlined process that emphasizes the advantages of prefabrication, such as reducing on-site construction time and labor costs;

(4) Fostering a talent pool proficient in prefabricated building technology is essential. Real-estate companies should invest in training programs to upskill their existing workforce and attract new talent. This ensures that the implementation of prefabricated building systems in real-estate development can be carried out smoothly with the necessary expertise.

Through these pathways, technological innovation in prefabricated building systems can be effectively realized in real-estate development.

2. Risk system construction for prefabricated projects

2.1. Theoretical framework of engineering risk management

The theoretical framework of engineering risk management provides the foundation for constructing a risk system in prefabricated projects. Engineering risk management encompasses the identification, assessment, and response to potential risks in a project [4]. In prefabricated projects, this framework helps in systematically analyzing various risks. For instance, design precision risk, if not properly managed, can lead to misfits during on-site assembly. Component quality risk might result in structural integrity issues. Supply chain coordination risk may cause delays in material delivery, affecting the project schedule. And on-site assembly reliability risk can impact the overall project quality.

The theoretical framework includes concepts such as risk probability and impact. Risk probability refers to the likelihood of a particular risk event occurring. Impact, on the other hand, measures the consequences if the risk materializes. By quantifying these aspects for each risk factor in prefabricated projects, project managers can prioritize risks. High-probability and high-impact risks need immediate attention, while low-probability and low-impact risks can be monitored. This framework also emphasizes risk response strategies, including risk avoidance, mitigation, transfer, and acceptance. For example, to avoid design precision risks, detailed design reviews and simulations can be carried out. To mitigate component quality risks, strict quality control measures during manufacturing can be implemented. Overall, a sound theoretical framework of engineering risk management is essential for effectively constructing a risk system in prefabricated projects.

2.2. Industry-specific risk characteristics

In prefabricated building projects, there are several distinct industry-specific risk characteristics. Technical maturity risks exist. The prefabricated building technology is still evolving. Some new manufacturing techniques and construction methods may not be fully tested in large-scale applications. For example, the durability and long-term performance of certain prefabricated components under different environmental conditions may not be thoroughly understood. This lack of technical maturity can lead to unforeseen problems during construction or in the later operation phase of the building [5].

Modular interface compatibility issues pose a significant challenge. Prefabricated buildings are composed of multiple pre-fabricated modules. Ensuring seamless compatibility between different modules in terms of size, connection methods, and functional requirements is crucial. Any mismatch in modular interfaces can disrupt the construction process, increase construction time and costs, and may even affect the structural integrity and functionality of the final building.

Workforce skill gaps are a notable risk factor. The construction of prefabricated buildings requires workers with specialized skills, such as knowledge of pre-fabrication processes, assembly techniques, and the use of new construction equipment. However, in the current construction industry, there is a shortage of such skilled workers. Workers who are accustomed to traditional construction methods may find it difficult to adapt to the requirements of prefabricated construction, which can result in low construction efficiency and potential quality problems.

3. Integrated innovation-risk interaction mechanisms

3.1. Technology-driven risk prevention systems

3.1.1. BIM-based collaborative design solutions

BIM-based collaborative design solutions play a crucial role in the technological innovation and risk prevention and control within real-estate project management, especially for prefabricated buildings. BIM technology enables multiple stakeholders, including architects, engineers, and contractors, to collaborate seamlessly in a shared digital environment. Through this, they can integrate various design information, such as architectural, structural, and MEP (Mechanical, Electrical, and Plumbing) details, into a single model [6].

This integrated model helps detect potential design conflicts early in the process. For example, clashes between different building components can be identified, which would otherwise lead to rework, cost overruns, and project delays during construction. In the context of prefabricated buildings, where components are manufactured off-site and then assembled on-site, accurate design coordination is even more critical.

Moreover, BIM-based collaborative design allows for virtual construction simulation. Project teams can simulate the construction sequence, analyze the logistics of transporting prefabricated components, and assess the overall construction schedule. This virtual preview helps in identifying potential construction-related risks, such as access issues, crane operation limitations, and scheduling bottlenecks. By addressing these risks in the design phase, project managers can optimize the construction process, enhance project efficiency, and reduce the overall risk exposure in real-estate project management for prefabricated buildings.

3.1.2. Intelligent quality control systems

Intelligent quality control systems play a crucial role in the technological innovation and risk prevention and control of prefabricated building real-estate projects. Throughout the production and installation phases, implementing RFID tracking and IoT-enabled component monitoring is an effective approach.

RFID tracking technology allows for real-time identification and location tracking of prefabricated components. Each component can be tagged with an RFID chip, which records detailed information such as production time, batch number, and quality inspection results. This enables project managers to accurately monitor the movement and status of components in the production line and during transportation and installation. For example, they can quickly identify any missing or damaged components, thus preventing potential delays and quality issues [7].

IoT-enabled component monitoring, on the other hand, uses sensors installed on components. These sensors can collect data on various parameters like stress, temperature, and humidity. In the production phase, this data helps ensure that components are manufactured under optimal conditions, reducing the risk of defective products. During installation, real-time sensor data can detect any abnormal conditions, such as excessive stress on a component, which may indicate improper installation. This early warning system gives managers time to take corrective actions, thereby enhancing the overall quality of the prefabricated building and effectively preventing risks associated with sub-standard quality.

3.2. Risk-informed technological optimization

3.2.1. Adaptive structural connection technologies

Adaptive structural connection technologies play a crucial role in Risk-Informed Technological Optimization within the realm of technological innovation and risk prevention and control in real estate project management, especially for prefabricated buildings. These technologies are designed to respond effectively to various risks associated with different structural demands and environmental conditions.

For prefabricated buildings, the connection between components is a key aspect that directly impacts the overall structural integrity and seismic performance. Post-tensioned precast concrete solutions offer a significant approach to innovate seismic-resistant jointing systems. This method involves applying post-tensioning forces to precast concrete elements after they are assembled. By doing so, it can enhance the load-bearing capacity and ductility of the connections.

The adaptive nature of these structural connection technologies lies in their ability to adjust to different levels of seismic forces. During seismic events, the post-tensioned connections can dissipate energy and reduce the likelihood of component failure. Moreover, they can also adapt to long-term service loads, ensuring the durability of the building structure. Through these adaptive structural connection technologies, real-estate project managers can better balance technological innovation and risk prevention, thus promoting the sustainable development of prefabricated buildings in the construction industry [8].

3.2.2. Supply chain resiliency enhancements

In the context of prefabricated building projects in real estate, enhancing supply chain resiliency is crucial for technological innovation and risk prevention. Creating vendor-managed inventory systems with blockchain-enabled logistics tracking is a key approach. This system, empowered by blockchain technology, can provide real-time, transparent, and immutable information about the movement of prefabricated components from suppliers to construction sites. For example, every stage of transportation, from the factory to the project location, can be accurately recorded, including details such as loading time, transit duration, and delivery status. This transparency helps project managers anticipate potential risks in the supply chain, such as delays or damage to components.

Additionally, with the traceability feature of blockchain, it becomes easier to identify the source of any problems that occur in the supply chain. In case of a defective prefabricated part, the entire production and transportation history can be traced back to determine the root cause, which is essential for timely corrective actions. This not only optimizes the supply chain but also reduces risks associated with inventory management and component delivery, thus enhancing the overall resiliency of the prefabricated building supply chain [9].

4. Case-based practical verification

4.1. High-rise residential project implementation

4.1.1. Technical innovation applications

In the implementation of a 40-story modular residential tower, lean construction techniques were comprehensively applied. In the pre-construction stage, through BIM technology, a three-dimensional model of the entire building was established. This allowed for accurate visualization of the project, enabling early detection and resolution of potential design flaws and construction interferences, thus reducing rework and waste during construction. For instance, by simulating the installation process of prefabricated components in the BIM model, the construction team could optimize the installation sequence and location, improving construction efficiency.

The just-in-time (JIT) delivery system was adopted for prefabricated components. This ensured that components arrived at the construction site exactly when needed, minimizing on-site storage space requirements and the risk of component damage due to long-term storage. Through close cooperation with component manufacturers and precise construction scheduling, the JIT system was effectively implemented.

Value-stream mapping was used to analyze the entire construction process. By identifying non-value-added activities, such as excessive material handling and waiting times, measures were taken to eliminate or reduce these activities. This led to a more streamlined construction process and enhanced overall project value. As a result, the project achieved significant improvements in construction quality, time-efficiency, and cost-control, demonstrating the practical effectiveness of lean construction techniques in high-rise prefabricated building projects [10].

4.1.2. Risk mitigation outcomes

In the implementation of high-rise residential projects using prefabricated building technology, remarkable risk mitigation outcomes have been achieved. By quantifying various aspects, it becomes evident that technological innovation plays a crucial role in risk prevention and control.

The construction duration has been reduced by 28%. Prefabricated building components are manufactured off-site in a factory-controlled environment, which significantly shortens the on-site construction time. This not only reduces the exposure to weather-related risks that could delay the project but also accelerates the overall project schedule, minimizing the risk of cost overruns due to extended construction periods [11].

Material waste has been decreased by 35%. In prefabricated building production, the manufacturing process can be precisely controlled. Factories can cut and process materials more accurately, reducing the amount of waste generated compared to traditional on-site construction methods. This not only mitigates the risk of environmental pollution caused by excessive waste but also leads to cost savings from reduced material consumption.

Safety incidents have decreased by 62%. With a large portion of the construction work shifted to the factory, the on-site construction environment becomes less complex. There are fewer workers on-site, and the work is more standardized. Factory-built components are then assembled on-site, reducing the potential for human-error-related accidents. This effectively reduces the safety risks associated with high-rise residential construction projects, ensuring the well-being of workers and the smooth progress of the project.

4.2. Mixed-use development challenges

4.2.1. Interface coordination complexities

In the context of prefabricated buildings, especially in a hybrid steel-concrete modular system, the MEP integration poses significant interface coordination complexities. For instance, in a large-scale prefabricated residential-commercial mixed-use development project, different modules made of steel and concrete have their own structural characteristics [12]. The steel modules may have higher strength but different thermal expansion coefficients compared to concrete modules. When integrating MEP systems, these differences need to be carefully considered.

The routing of electrical conduits and plumbing pipes becomes a challenge. In steel modules, the attachment methods for conduits may differ from those in concrete modules. In concrete modules, conduits are often embedded during the casting process, while in steel modules, they may need to be attached using special brackets or clamps. Moreover, the location of mechanical equipment interfaces, such as air-conditioning units, also needs to be precisely coordinated. If not properly planned, it can lead to conflicts between different MEP subsystems and the structural components of the hybrid modules.

The coordination between different trades also presents difficulties. Electrical engineers need to communicate effectively with plumbing engineers and structural engineers to ensure that the MEP systems do not compromise the structural integrity of the hybrid modules. Any misalignment or oversight in interface coordination can result in costly rework during the construction phase or potential operational problems in the future.

4.2.2. Adaptive project management strategies

In the context of prefabricated building real estate project management, mixed-use development poses unique challenges. For instance, in a large-scale urban development project integrating residential, commercial, and public service facilities, the diverse requirements from different user groups need to be met simultaneously. The design of prefabricated components must consider not only the functional needs of each use type but also the overall aesthetic and structural integrity of the complex.

Agile project delivery methods can play a crucial role in addressing these challenges. By closely collaborating with various stakeholders, including architects, contractors, and end-users, real-time adjustments can be made to the project plan. In a case where a commercial area within a mixed-use development needed to be reconfigured due to changes in market demand, the agile approach enabled the project team to quickly modify the prefabrication plans, reducing waste and delay.

However, implementing agile methods also has its own risks. The lack of a detailed upfront plan might lead to unforeseen technical issues in prefabrication. To mitigate these risks, a hybrid approach can be adopted, combining the flexibility of agile with some elements of traditional project management. This ensures that while responding to changes, the project still adheres to fundamental quality and safety standards in prefabricated building construction [13].

4.3. Industrialization transformation pilot

4.3.1. Policy-driven innovation models

In the industrialization transformation pilot of prefabricated buildings, policy-driven innovation models play a crucial role. National demonstration projects provide an ideal platform to examine government-industry collaboration mechanisms. For instance, in some regions, local governments have introduced preferential policies such as land-use incentives, financial subsidies, and tax breaks for real-estate developers engaging in prefabricated building projects [14]. These policies not only reduce the financial burden on developers but also encourage them to actively participate in the innovation and application of prefabricated building technologies.

At the same time, the government has strengthened cooperation with industry-leading enterprises. By jointly formulating industry standards and technological specifications, it ensures the quality and safety of prefabricated buildings. These industry-wide standards not only provide a clear direction for the production and construction of prefabricated components but also promote the healthy development of the entire prefabricated building industry.

Moreover, policy-driven innovation models also involve promoting technological R&D through government-led research projects. The government allocates special funds to support joint research by enterprises, universities, and research institutions, aiming to break through key technological bottlenecks in prefabricated building construction, such as improving the connection technology of prefabricated components and enhancing the energy-saving performance of prefabricated buildings. This collaborative innovation approach effectively integrates various resources, accelerates the technological innovation process in the prefabricated building field, and helps to better prevent and control risks in real-estate project management.

4.3.2. Market adoption barriers

The perception of lifecycle costs significantly influences the market adoption of prefabricated building technology. Stakeholders often have misperceptions. For instance, developers may be overly focused on the upfront high investment in prefabricated building components and production facilities. They fail to fully consider the long-term savings in construction time, labor costs, and maintenance expenses over the building's lifecycle. This short-sighted view acts as a deterrent to their enthusiasm for adopting prefabricated building technology.

Regulatory hurdles also play a crucial role. The current regulatory framework may not be well-tailored to the unique characteristics of prefabricated buildings. Building codes and standards may lack clear guidelines on aspects such as component connection techniques, quality inspection procedures specific to prefabricated elements, and fire-resistance ratings for prefabricated structures. This lack of clarity creates uncertainties for both developers and construction teams. In addition, the approval process for prefabricated building projects may be more complex due to the need to review new construction methods and technologies. As a result, the regulatory environment becomes a barrier, impeding the smooth market penetration of prefabricated building technology.

5. Conclusion

In conclusion, this paper has delved into the intricate symbiotic relationship between technological innovation and risk prevention and control within the context of prefabricated building project management in the real estate sector. The findings underscore the significance of a three-dimensional development model. Technical standardization serves as the bedrock, ensuring that every aspect of prefabricated construction, from design to assembly, adheres to a set of unified and optimized norms. This not only streamlines the construction process but also reduces uncertainties and potential risks associated with inconsistent practices.

The integration of risk intelligence systems is another crucial dimension. By leveraging advanced data analytics and real-time monitoring technologies, these systems can proactively identify, assess, and mitigate risks, thereby enhancing the overall resilience of prefabricated building projects. Stakeholder collaboration frameworks, on the other hand, foster an environment of open communication and shared responsibility among all parties involved, from architects and contractors to suppliers and end-users.

Looking ahead, future research should focus on two main areas as follows:

(1) AI-driven risk prediction: As AI continues to evolve, its potential in accurately forecasting risks in prefabricated building projects is vast. This could involve developing more sophisticated algorithms that can analyze a multitude of variables, from weather patterns to supply chain disruptions;

(2) The application of the circular economy in modular components: Exploring ways to recycle, reuse, and remanufacture these components can not only reduce environmental impact but also bring about cost-savings and new business models in the prefabricated building industry.

Overall, these efforts will contribute to the sustainable and efficient development of prefabricated buildings in real estate project management.

Disclosure statement

The author declares no conflict of interest.

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