Exploration of Innovative Paths for Construction Engineering Construction Technology Management

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Abstract: In the context of the global construction industry's rapid development, construction engineering construction technology management is crucial. Traditional models face challenges like complexity, lack of digitalization, and poor collaboration. Innovative paths include digital transformation, sustainable construction, and integration of new technologies. Performance evaluation and policy support are vital. Future research could focus on AI-optimized management and cross-industry convergence.

Keywords: Construction technology management; Innovative paths; Sustainability

1. Introduction

In the era of the global construction industry's rapid development, construction engineering construction technology management is of utmost importance. The "14th Five-Year Plan for the Development of the Construction Industry" (issued in 2021) emphasizes promoting the digital transformation and green development of the construction industry. Amidst the emergence of new materials, techniques, and equipment, traditional management models face challenges. Thus, exploring innovative paths is crucial. For instance, Zhou *et al.* proposed a digital twin-enabled sustainability management framework, which demonstrates how digital technologies can enhance sustainability performance in construction projects [1]. This paper delves into various innovative approaches, analyzes their pros and cons, and seeks effective strategies. It aims to contribute to the industry's sustainable development, helping construction companies adapt to market and technological changes, and ultimately achieve high-quality construction projects.

2. Current status and challenges

2.1. Analysis of current construction technology management practices

The current construction technology management in construction engineering mainly follows the conventional management models. Standardization processes are implemented to ensure that construction operations are carried out in an orderly manner. For example, specific procedures are set for each construction stage, from foundation laying to superstructure building. Quality control mechanisms play a crucial role in guaranteeing the project quality. Inspections are regularly conducted at different construction phases, and strict quality standards are adhered to. Safety protocols are also an essential part, aiming to protect the safety of construction workers and the public. Warning signs are placed at construction sites, and safety training is provided to workers.

However, there are still some challenges as follows:

(1) The complexity of construction projects often leads to difficulties in implementing these management practices effectively. Different types of projects may require specific management adjustments, but the current models may lack flexibility;

(2) The rapid development of construction technology means that the existing management models may not keep up with the changes. New technologies may bring new management requirements, such as the management of building information modeling (BIM) technology [2];

(3) In some cases, there may be a lack of coordination among different management aspects, for instance, between quality control and safety management, which may affect the overall project progress and quality.

2.2. Key challenges in traditional management approaches

The traditional management approaches in construction engineering construction technology management face several key challenges as listed.

(1) The low level of digitalization is a significant issue. In traditional setups, much of the work still relies on manual methods, paper-based documentation, and face-to-face communication. This not only leads to inefficiencies in data collection, storage, and retrieval but also increases the risk of human errors [3]. For example, the process of updating construction schedules often involves a lot of manual input and re-input, which can be time-consuming and prone to mistakes.

(2) Collaboration efficiency among different parties is poor. In construction projects, multiple stakeholders such as contractors, designers, suppliers, and subcontractors are involved. Traditional management approaches lack effective real-time communication and coordination mechanisms. As a result, information silos are common, causing delays in decision-making, misunderstandings, and rework. For instance, designers may not be promptly informed of on-site changes made by contractors, leading to inconsistent construction according to the original design;

(3) The integration of sustainability is insufficient. Traditional management mainly focuses on cost, quality, and schedule, often overlooking environmental and social aspects. With the growing global emphasis on sustainable development, this short-sightedness can no longer meet the requirements of modern construction projects. For example, energy-saving measures and waste reduction during construction may not be properly planned and monitored due to the lack of a comprehensive sustainability management framework in traditional approaches.

3. Theoretical framework for innovation

3.1. Principles of technological innovation in construction

The principles of technological innovation in construction are pivotal in the context of exploring innovative paths for construction engineering construction technology management. With the integration of Industry 4.0, the construction industry is undergoing a digital and intelligent transformation. Industry 4.0 emphasizes the combination of cyber-physical systems, which enables real-time monitoring, control, and optimization of construction processes. For example, sensors can be installed on construction equipment and building components to collect data on performance, wear, and structural integrity, facilitating predictive maintenance and quality control [4].

The concept of circular economy also plays a crucial role. It encourages the reduction, reuse, and recycling of construction materials. In construction, this could involve using reclaimed materials in new projects, designing buildings for disassembly to enable easy material recovery at the end of their life cycle, and minimizing waste generation during construction. This not only reduces environmental impact but also cuts costs in the long run.

Intelligent construction principles focus on leveraging emerging technologies such as artificial intelligence (AI), machine learning, and the Internet of Things (IoT). AI can be used for tasks like project scheduling optimization, risk prediction, and decision-making support. The IoT allows for seamless connectivity between various construction devices and systems, enabling more efficient resource management and enhanced safety on construction sites. By adhering to these principles of technological innovation, the construction industry can enhance its competitiveness, improve productivity, and achieve sustainable development.

3.2. Management theory integration

The theoretical framework for innovation management theory integration in construction engineering construction technology management aims to explore the synergies among lean construction philosophy, agile management frameworks, and risk mitigation methodologies. Lean construction philosophy emphasizes eliminating waste, optimizing processes, and enhancing value-creation in construction projects [5]. By streamlining workflows, reducing non-value-added activities, and promoting continuous improvement, it can improve construction efficiency and quality. Agile management frameworks, on the other hand, focus on flexibility, adaptability, and rapid response to changes. In the dynamic construction environment, where unforeseen events often occur, agile principles enable project teams to quickly adjust plans, re-allocate resources, and make informed decisions. Risk mitigation methodologies are crucial for identifying, assessing, and addressing potential risks in construction projects. By integrating these three aspects, construction firms can create a comprehensive approach to innovation. Lean principles can help in making the project process more efficient, which in turn reduces the probability of risks. Agile management allows for swift responses to emerging risks and changes. Risk mitigation methodologies, meanwhile, provide the necessary tools to ensure that the lean and agile approaches can be implemented smoothly. This integrated theoretical framework serves as a foundation for guiding construction engineering construction technology management towards more innovative paths.

4. Innovative paths and methodologies

4.1. Digital technology applications

4.1.1. BIM-based collaborative management platforms

BIM-based collaborative management platforms play a crucial role in the innovative paths of construction

engineering construction technology management. By implementing building information modeling, real-time project monitoring becomes feasible. This digital technology allows all project stakeholders, including architects, engineers, contractors, and clients, to access a unified and up-to-date model of the construction project. Every change made in the design, construction progress, or material selection is immediately reflected in the BIM model, enabling real-time tracking of the project's status [6].

Moreover, BIM-based platforms facilitate cross-disciplinary coordination. In traditional construction projects, communication gaps between different disciplines often lead to inefficiencies, errors, and delays. However, with a BIM-based collaborative management platform, different teams can work on the same digital model simultaneously. For example, the structural engineering team can interact with the mechanical and electrical engineering teams. They can identify potential clashes between structural elements and MEP systems in the virtual model before construction begins. This cross-disciplinary interaction streamlines the construction process, reduces rework, and improves the overall quality of the project. In essence, the BIM-based collaborative management platform serves as a digital hub that integrates various aspects of construction technology management, fostering innovation and efficiency in construction engineering.

4.1.2. IoT-driven smart construction sites

In IoT-driven smart construction sites, sensor networks play a pivotal role. These sensors are strategically deployed across the construction site, on various equipment, and at key construction areas. They can collect a vast amount of real-time data, such as equipment operating status, environmental conditions like temperature and humidity, and the stress levels of building structures [7].

The high-level equipment interconnectivity in this context is a game-changer. It allows different construction machines and devices to communicate with each other. For example, a crane can share its load - bearing data with the control system, which can then adjust the operations of other nearby equipment to ensure overall site safety and efficiency.

This seamless data flow enables predictive maintenance. By analyzing the data collected from sensors, construction managers can predict when a piece of equipment is likely to fail. Instead of waiting for a breakdown, maintenance teams can be dispatched in advance to fix potential issues. This not only reduces unplanned downtime but also extends the lifespan of the equipment, thus saving costs.

Moreover, data-driven decision-making becomes possible. Construction supervisors can base their decisions on the comprehensive data analytics. For instance, they can optimize construction schedules according to the real-time progress data, or allocate resources more effectively by understanding the usage patterns of different materials and equipment. In essence, IoT-driven smart construction sites revolutionize traditional construction management through enhanced data collection, connectivity, and decision-making processes.

4.2. Sustainable construction strategies
4.2.1. Green construction technology integration

Green construction technology integration involves evaluating low-carbon material applications and energy-efficient construction methodologies. Low-carbon materials are the cornerstone of sustainable construction. For instance, recycled materials such as recycled concrete aggregates can significantly reduce the environmental impact associated with the extraction of virgin materials. These materials not only help in conserving natural resources but also lower the carbon footprint during their production process [8]. Another example is the use

of bamboo, a fast-growing and renewable material, which can be used for various construction elements like scaffolding and even structural components in some cases.

Regarding energy-efficient construction methodologies, prefabrication and modular construction are gaining popularity. Prefabrication allows for better control over the manufacturing process, reducing waste and enabling more efficient use of energy during construction. Modular construction, on the other hand, can be assembled on-site quickly, minimizing construction time and thus reducing energy consumption related to construction activities. Additionally, energy-efficient building envelopes are crucial. This includes high-performance insulation materials and energy-efficient glazing systems. These technologies help to reduce heat transfer, thereby decreasing the energy required for heating and cooling, and contributing to the overall energy efficiency of the building.

4.2.2. Circular economy implementation models

Throughout the project lifecycles, construction engineering should focus on proposing resource recycling systems and waste minimization frameworks to implement circular economy models. For resource recycling systems, materials like steel, concrete, and wood can be carefully sorted, processed, and reused on-site or in other projects. For example, demolished concrete can be crushed and used as aggregate for new concrete production. This not only reduces the demand for virgin materials but also cuts down on the energy and environmental impact associated with their extraction and processing [9].

Regarding waste minimization frameworks, a comprehensive waste management plan should be formulated at the project's onset. This includes accurate material quantity estimation to avoid over-ordering, as well as efficient construction sequencing to reduce material waste caused by rework. Additionally, promoting pre-fabricated construction can significantly minimize waste generated during on-site construction. By standardizing components and assembling them at the construction site, the amount of construction waste can be effectively reduced. These circular economy implementation models not only contribute to environmental protection but also bring economic benefits in the long run through cost-savings on materials and waste disposal.

5. Case studies and practical implementation

5.1. Innovative project demonstrations

5.1.1. High-rise building digital twin implementation

In the context of high-rise building digital twin implementation, a compelling case study focuses on the integration of virtual reality (VR) for structural safety management in skyscraper projects [10]. In this project, a digital twin of the high-rise building was first created, accurately mirroring every structural detail, from the foundation to the top-most floor. The digital twin served as a virtual replica that could simulate various scenarios.

For structural safety management, VR technology was then integrated. Engineers could immerse themselves in the virtual environment of the digital twin. They could closely inspect joints, columns, and beams, which was difficult to achieve in the real-world physical building during the construction process. This immersive experience enabled them to detect potential structural flaws in advance. For example, by virtually walking through the building's framework, they identified a misalignment in a critical load-bearing column that could have led to significant safety issues if left undetected.

The practical implementation of this high-rise building digital twin with VR integration also enhanced communication among different stakeholders. Architects, contractors, and safety inspectors could use the digital twin in VR to discuss design changes, construction progress, and safety measures. This not only improved

the efficiency of decision-making but also ensured that the final construction met the highest structural safety standards. Overall, this case study showcases an innovative approach to high-rise building construction through digital twin implementation with VR for structural safety management.

5.1.2. Prefabrication facility automation case

In the prefabrication facility automation case within modular construction plants, the robotic assembly line optimization plays a pivotal role. Consider a modular construction project where the prefabrication facility aimed to enhance production efficiency and quality. Initially, the assembly line faced issues such as long cycle times and inconsistent product quality. To address these, a detailed analysis of the robotic assembly line was carried out. The movement paths of robots were re-engineered to reduce unnecessary travel distances. By using advanced simulation software, different configurations of the robotic workstations were tested. This enabled the identification of the most efficient layout in terms of material flow and robot-to-robot cooperation. Additionally, sensors were integrated into the robotic systems to improve the precision of component handling and assembly. These improvements led to a significant reduction in production errors. As a result, the plant witnessed a remarkable increase in daily production output, with the number of high-quality modular components rising substantially. This case not only showcases the practical application of robotic assembly line optimization in prefabrication facilities but also aligns with the broader need for workforce development in a digitalized construction environment, serving as a valuable example for other construction projects seeking to enhance their automation levels in modular construction [11].

5.2. Performance evaluation metrics

5.2.1. Cost-benefit analysis framework

In the practical implementation of construction engineering construction technology management, the cost-benefit analysis framework plays a pivotal role. By establishing quantitative evaluation models to assess technological return on investment (ROI) and lifecycle costs, construction firms can make more informed decisions. For example, in a high-rise building project, the implementation of prefabricated construction technology was evaluated [12]. The initial investment in prefabrication facilities and component production was calculated as the cost part. On the benefit side, factors such as reduced construction time, labor savings, and enhanced quality control were considered. The time saved led to earlier occupancy, generating revenue sooner. Labor savings directly cut down on payroll expenses.

The technological ROI was calculated by dividing the net benefits (total benefits minus total costs) by the initial investment in the technology. The lifecycle cost assessment took into account not only the construction-phase costs but also maintenance, repair, and demolition costs over the building's lifespan. This comprehensive cost-benefit analysis framework enabled the project team to compare different construction technologies objectively. It also helped in justifying the adoption of innovative technologies, as it clearly demonstrated the long-term economic advantages. Such case-based practical implementation of the cost-benefit analysis framework can guide other construction projects in optimizing their technology management strategies and achieving better economic and performance outcomes.

5.2.2. Sustainability impact assessment

In the context of construction engineering construction technology management, sustainability impact assessment

is crucial. It involves the use of developed carbon footprint calculation methodologies and environmental performance indicators. For instance, in a large-scale commercial building project, by applying the carbon footprint calculation methodology, the project team can precisely quantify the amount of carbon emissions generated during different construction phases, from material extraction and transportation to on-site construction activities. This quantification helps in identifying high-carbon-emitting processes and taking targeted measures to reduce emissions.

Regarding environmental performance indicators, they can cover aspects such as energy consumption, water usage, and waste generation. In a residential construction case, monitoring energy consumption through these indicators enables the assessment of the energy-efficiency of construction equipment and building systems. If the energy consumption exceeds the set benchmark, it prompts the adoption of more energy-efficient technologies.

Moreover, the sustainability impact assessment not only focuses on environmental aspects but also considers social and economic impacts. Socially, it may involve evaluating the impact on local communities, such as noise pollution during construction affecting residents' living quality. Economically, it assesses the long-term cost-effectiveness of sustainable construction technologies. By conducting such comprehensive sustainability impact assessments in case studies and practical implementation, construction engineering construction technology management can better achieve sustainable development goals [13].

5.3. Implementation strategy formulation

5.3.1. Workforce skill transition programs

In the context of construction engineering construction technology management, workforce skill transition programs play a pivotal role. To start with, training systems designed to enhance digital literacy are of great significance. Digital tools such as BIM have become integral in modern construction projects. By offering comprehensive BIM training, workers can better visualize projects, detect potential clashes in design, and improve overall project coordination. This not only streamlines the construction process but also boosts efficiency and accuracy.

Moreover, programs focused on cross-functional competency development are equally essential. Construction projects involve multiple disciplines, from architecture and engineering to project management. Workers with cross-functional skills can bridge communication gaps between different teams, ensuring seamless collaboration. For instance, construction engineers trained in basic project management principles can better understand project timelines, budgets, and client requirements, thus contributing to the project's success. These training initiatives should be carefully structured, incorporating theoretical knowledge, hands-on practice, and real-world case studies [14]. By doing so, the construction workforce can adapt to the ever-evolving technological landscape in construction engineering, leading to more innovative and efficient construction technology management practices.

5.3.2. Policy support mechanism design

Regarding the policy support mechanism design for the exploration of innovative paths in construction engineering construction technology management, it is essential to recommend regulatory frameworks. These frameworks should be formulated to actively promote the adoption of new technologies in the construction industry. For example, they can set clear standards and guidelines for the use of emerging construction technologies such as BIM, prefabricated construction, and green building technologies. By doing so, construction companies will have a clear direction on how to integrate these technologies into their projects.

In addition, the regulatory frameworks should also incorporate innovation incentives. These incentives

can be in various forms. Financial incentives like tax breaks, subsidies, or low-interest loans can be provided to construction enterprises that invest in research and development of new construction technologies or adopt innovative construction methods. Non-financial incentives such as public recognition, awards, and preferential treatment in government-led construction projects can also stimulate the enthusiasm of construction companies for technological innovation. Through these well-designed regulatory frameworks and innovation incentives, the construction engineering industry can be effectively driven to embark on a path of continuous technological innovation and improvement in construction technology management.

6. Conclusion

In conclusion, the exploration of innovative paths for construction engineering construction technology management has revealed the necessity of a profound shift from traditional management models. The construction industry is at a critical juncture where digital transformation and a focus on sustainability are no longer optional but essential for its long-term viability. The research findings have underscored the potential of digital technologies in enhancing efficiency, accuracy, and decision-making in construction technology management. By leveraging digital tools, construction firms can streamline processes, reduce errors, and achieve greater transparency in project execution. Additionally, the drive towards sustainability in construction technology management is not only an environmental imperative but also a strategic advantage in the market. Looking ahead, future research should delve deeper into AI-optimized project management. AI has the potential to revolutionize how construction projects are planned, monitored, and controlled. It can predict potential risks, optimize resource allocation, and improve overall project performance. Moreover, cross-industry technological convergence holds great promise. By integrating technologies from other sectors such as aerospace, automotive, and information technology, the construction industry can access new materials, methods, and management strategies. This exploration of innovative paths in construction engineering construction technology management will continue to shape the industry, driving it towards a more efficient, sustainable, and technologically advanced future.

Disclosure statement

The author declares no conflict of interest.

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