

An Analysis of the Application of Digital Twin Technology in Smart Construction

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Abstract. Based on the practical construction experience of the Shuangtang Industrial Plant Project in Wenling, Zhejiang, this paper systematically explores the practical application value and technical advantages of digital twin technology in the field of smart construction. This advanced technology establishes real-time dynamic virtual-physical mapping between digital models and on-site entities, integrating scattered full-cycle construction data to support refined and precise management of construction progress, building materials, on-site personnel and mechanical equipment. It effectively addresses prominent pain points in traditional construction, including low operational efficiency, high comprehensive project costs, and inadequate safety supervision and quality control, further promoting the construction industry's transformation toward digital, intelligent and low-carbon green management. Nevertheless, the large-scale and extensive application of this technology is still restricted by multiple bottlenecks, including heavy reliance on foreign core technologies, uneven full-lifecycle application distribution, the absence of unified industrial data standards and inefficient cross-departmental collaborative work. In the future, digital twin technology will gradually evolve into lightweight, platform-integrated systematic solutions that cover the entire building lifecycle, which requires continuous independent R&D innovation, unified industrial data norms and the establishment of a sound collaborative industrial ecosystem.

Keywords: digital twin, smart construction, full-cycle construction data, refined construction management, industrial data standards.

1. Introduction

The building sector is a backbone of the world economy. Nonetheless, the conventional growth strategy has much to do with inadequacies with respect to technology implementation, efficiency in management, quality and safety, utilization of resources, environmental conservation, risk mitigation, and management of the life cycle, thus it cannot satisfy the requirements of the industry of high-quality growth. In the context of significant penetration of the digital economic environment and the construction industry engineering, smart construction technology is the backbone of the digitalization process in the industry and the central pillar of the high-quality development drive in the engineering sphere [1-3]. Although digital twins, being the main technologies that link the physical and virtual worlds might address the fragmentation of construction information [4], its use in the construction industry is in infancy and still experimental. The fact that they have inconsistent technical standards, low cross-scenario flexibility, are not multidisciplinary friendly, costly to implement, and have no systematic planning and assessment systems is among those factors that make their implementation less frequent [5].

Considering these issues of the industry, the present paper initially defines the main concepts related to the smart construction technology, examines the situation in the Chinese construction industry and the conditions of using smart construction technology, and states the central direction of technological changes taking place in the sphere. Simultaneously, it chooses the project of the industrial plant of the Shuangtang, located in the city of Daxi in the province of Zhejiang, as an example that can be used in-depth to investigate the implementation paths and the application value of digital twins technology in the context of smart construction. The study has both theoretical and practical utility. In theory, it sharpens the theoretical model of integrating digital twins and smart construction, explaining their inner logic and mechanisms of their utilization; in practice, it gives

practicable recommendations on how to implement the digital twin technology, and hence helps to drive the digital, green and low-carbon shift of the construction industry.

2. Applications of digital twins in smart construction

2.1. Overview of smart construction and digital twin

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The affiliations of authors must be typed in 9-point Times. These affiliations should have a numerical superscript that will come before them which is also equal to the superscript after the name of the author in question. Make sure your affiliations contain as much detail as feasible and indicate a country [6].

2.2. Applications

Smart Construction, as a concept, involves the creation of virtual models using digital twins and real-time communication between physical structures, creating an innovation in the digitalization, visualization and smart management of the whole construction process; they can be used in the design and construction stages and also in the operational preparation and maintenance stage. A model of digital twins is constructed during the design phase upon the highly- accurate Building Information Modeling (BIM) models. Simulations, clash detections and performance optimization are performed virtually, which enhances quality of the design at the source and minimizes design changes during the construction process.

BIM is used as the repository of the project data during the construction phase; the parametric models of BIM offer an intuitive representation of key information about construction schedules and resource allocation that facilitates virtual construction rehearsals and dynamic optimisation [7]. Through 4D construction simulation technology, the presence of work process disputes may be identified in advance, and adjustments in construction plans could be made to reduce cost losses due to redesigns and rework. The peak usage of digital twins is in the construction phase itself. With a combination of Internet of Things (IoT), 5G, and edge computing technologies, up-to-date information on personnel in the field, machinery, material and environment may be synchronized with the digital twin platform, making it possible to control and manage everything in the process in real-time. Through the use of 4D models to simulate progress and dynamic scheduling, technical systems are used to implement overall digital tracking of prefabricated parts and bulk material throughout their arrival at site to their installation; Artificial Intelligence (AI) video surveillance solutions automatically detect unsafe situations and send out real-time alerts, and smart measurement robots carry out high precision tasks and quality control; IoT sensing systems facilitate smart management of construction materials storage facilities and logistics, supplying consistent construction material flow. At the operations and maintenance preparation stage, the completed digital twin model becomes the fundamental digital asset of the building handover, which provides strong data backing to the future smart facilities management, energy monitoring as well as emergency response [8].

Although the practicality of digital twins has been proven in some projects, there is still a long way to go before their use becomes widespread in the construction industry [9]. This process of roll-out is a source of many common problems, which require developing optimization strategies at various levels. To overcome the heavy dependence on imported core technologies and the excessive entry barriers, more efforts need to be exerted towards independent development of local BIM software, IoT systems, and basic algorithms, thus creating a safe and manageable technological environment. Meanwhile, less expensive modular solutions also ought to be created so as to minimize project application expenses with smaller and medium-sized projects. To counteract the disparity in

the application that is defined by a focus on building, disregard operation and maintenance there must be clarification of the overall lifecycle value of digital twin models at the initial stages of planning the project. The creation of data standards and update methods of operation and maintenance, innovation of business models and expansion of novel service formats should be considered to run digital twin operations and maintenance. In order to solve such problems as the absence of consistent standards in the industry data, lack of coordination among the entities of the industrial chain [10], the state and professional unions can play the leading role in the development of unified industry standards including the formats of data, interface interactions and deliverables [11]. There should be a promotion of the concept of integrated management of EPC, and contractual obligations and integrated platforms employed to ease the process of sharing data and conducting businesses between multiple parties. The optimisation of design space conflicts, hoisting hazards and quality risks can be pre-emptively predicted through digital simulation and optimisation. Through the use of the visualization and parametric functions of BIM and digital twins to optimize the design solutions, this methodology will provide repeatable technical solutions and managerial skills of engineering practice.

3. Analysis of a typical case study

The Daxi Shuangtang Industry Park project in Wenling city, Zhejiang province will be discussed as a thesis topic. The project acts as a paradigm of synchronized smart construction and new construction industrialization with integrated application of a smart construction technology network including BIM, digital twins and intelligent gadgets.

3.1. Application of digital twin technology

The project created a closed-loop digital control system including design, construction, and operational and maintenance setup by attaining the concept-based management at all stages of the process. At the design stage, a digital twin model was created based on detailed, multi-disciplinary BIM models. Visual simulations were carried out after several rounds of simulation, clash detection and optimization of performance in critical junctions with respect to complex construction processes, integrated piping and ductwork arrangements, as well as large scale equipment lifting routes. Overall, 32 vital design nodes were optimized which will improve the design quality at its source, minimize construction changes, and form a basis of efficient construction.

Construction is the vital phase where you implement the concept of the digital twin technology [12]. The project has created a unified digital twin control system, which was based on use of 5G networks and edge computing hardware to ensure real time synchronisation of all on-site dynamics data with the virtual image. The whole flow of precast components delivery, storage and installation process was intelligently monitored and coordinated in aerial photography with drones and radio frequency tracking RFID technology; Intelligent video surveillance system can automatically detect safety risks, like workers without hard hats, unauthorized access to dangerous regions, and alarm you immediately, to minimize safety incidents; automated equipment such as smart hoists and surveyor robots perform more than 90 percent of high-intensity repetitive tasks, limiting error in construction measurements to less than 2 millimeters, and thus, guaranteeing the overall quality of the physical structure.

3.2. Application outcomes

The digital twins have also provided enormous and measurable benefits to this project. When it comes to effectiveness and expenses, construction effectiveness has grown by about 30 percent, labour expenses have decreased by 35 percent, the rework ratio has declined by 40 percent, and construction time has been minimised by close to a month. It can be mostly explained by optimisation of construction organization based on 4D progress simulation, dynamic scheduling, and smart material tracking, which has minimized waiting, searching and reworking time.

The project included the application of intelligent measurement robots and 3D laser scanning technology in terms of quality and precision control. Along with automated comparison and checking with the digital twin model, it ensured that the error of construction accuracy was not more than 2 millimeters. Automated inspection was applied to more than 90 percent of repetitive and high-intensity measuring tasks allowing fine control of the quality of engineering through computerization. With regard to safety management, the AI video surveillance system may be used to detect and send real time alerts on possible safety threats. The combination of virtually simulating high-risk work and the completion of the project have contributed to zero major safety accidents occurring during the whole construction phase, which sets as a new paradigm of proactive prevention-based safety management.

4. Conclusion

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According to the practice of the Shuangtang Industrial Plant Project in Daxi, Wenling, Zhejiang, it can be summarized that the digital twin is one of the major enabling technologies behind smart construction development. Through the creation of a dynamic link between physical structures and virtual design, it brings unity to the data chain within the whole building process, allowing to manage construction process, materials, construction staff and equipment precisely, and efficiently solving the problem of the fragmentation of information in the traditional construction. This technology has proven to be highly effective in improving the efficiency of construction, cost control, and safety and quality of projects, and can successfully solve the critical problems with low efficiency, high costs, and inability to effectively manage quality and safety in traditional construction.

The digital twin technology can be used in a flexible way during various project conditions. The project with a high degree of precision and efficiency like industrial plants may meet the managerial requirements and control needs perfectly and allow the optimal distribution and dynamic planning of resources, which underlines the usefulness and versatility of the technology. Smart construction has been brought to the forefront by the deep integration of digital twins and smart construction, which has led to the improvement of the smart construction technologies structures, and thus, the transformation of extensive management to intelligent, digitalized and green management within the construction industry. It forms the backbone of technological advancement in the industry that promotes high value development of the industry and ensures that value is maximized at each stage along the building lifecycle.

However, in the future, the use of digital twins and smart construction will have some new developmental features. At present, its development can be hindered by various practical issues, which are most prominently reflected in excessive dependence on external core technologies, lack of equilibrium in whole-cycle applications, non-uniformity in industry data standards, and problems with coordination of the supply chain process. Technically, the sector is moving towards a platform-based and lightweight solution model that will further reduce access barriers to the applications and deployment costs; the area of application will start to cover the core construction stage and eventually cover the entire lifecycle of planning and design, construction implementation, operation, and maintenance.

In order to realize the mass application of digital twin technology, it is necessary to create an open and cooperative industrial ecosystem, whereby the development of common data standards and communication protocols will be a major requirement. The next wave of research ought to explore tailored implementations of various types of projects; innovative supporting business models and

regulatory frameworks, as well as full support of implementing the digital twin technology and digitally transforming construction.

Authors contribution

All the authors contributed equally and their names were listed in alphabetical order.

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