Exploration of Digital Transformation Path of Construction Engineering Management in the Background of Smart Construction

Shanwen Shi

Anhui Gaoyue Construction Engineering Co., Ltd., Hefei, Anhui, 230000, China

Keywords: Smart Construction; Construction Project Management; Digital Transformation; Information Integration; Intelligent Construction

Abstract: Driven by the digital economy and the new urbanization process, the construction industry is accelerating its transition toward smart construction. To promote high-quality development of the industry, IT digital transformation of construction engineering project management has become a major direction. These integrated models are beset by information silos, fragmented processes, and low efficiency levels, making them ill-equipped to satisfy the requirements for increased collaboration, accuracy, and intelligence found in complex engineering projects. In this paper, we investigate digital transformation pathways regarding construction project management in the scope of smart construction. It explains the what and why of smart construction and digital transformation dynamics in construction programme/portfolio management, showing how policy direction and technical advancements are positioned as well as formally-ended labour market value creation asks for replacing or enhancing right tools. Three dimensions are analyzed in this transformation pathway: the interaction between digital platforms and information integration, intelligent technology-driven construction management, and collaborative management by means of organizational transformation. It summarizes the challenges faced during transformation, such as standardisation issues, high-cost investment, data security, and talent shortages and the countermeasures that can be taken in response to these challenges. Digital transformation will not only improve project management, efficiency, and resource allocation but also inject new momentum into the sustainable development of construction companies. Under the application of emerging technologies such as artificial intelligence, blockchain and the metaverse, construction project management will step into a new stage of intelligence and smartization.

1. Introduction

The digital economy era has arrived, the new urbanization is continuing to promote, and the construction industry has entered a critical stage from extensive development based on traditional practices to intelligent and refined development [1]. As a result of the in-depth integration of information technology and construction industry, smart construction can not only change the organization mode and production pattern of engineering projects, but also enable different perspectives on upgrading construction project management [2]. Construction project management has been popularly driven through traditional techniques for decades, and has suffered from disparate information, ineffective communication channels, and inefficient processes [3]. This imposes challenges for large, complex projects that require efficient collaboration and dynamics control [4]. Digital transformation of construction project management has become the only way for enhancing the core competitiveness and achieving high-quality development in the industry [5]. Digital management collects big data, the Internet of Things, artificial intelligence and cloud computing at this stage can be used to realize information integration and dynamic monitoring throughout project life cycle [6]. This strengthens the quality, safety, cost and schedule control of projects as well. In the context of smart construction focusing on sustainable development, it discusses the essence and implementation paths for digital transformation in construction project management as well as analyzes its challenges, providing corresponding countermeasures that contribute to provide guidance on how to achieve innovative management in the sustainable development of the construction industry [7].

Copyright © (2025) Francis Academic Press, UK DOI: 10.25236/icacel.2025.111

2. Smart Construction and the Essence & Drivers of Digital Transformation in Construction Project Management

Smart construction is a new paradigm that focuses on informatization, digitization, and intelligence [8]. The focus of BIM is on the efficient collaboration and dynamic optimization process in the entire project life cycle, combined with next-generation IT (information technology) systems deeply integrated with each other [9]. Smart construction is different from traditional construction — it mainly highlights data-driven intelligence decision-making and intelligence operations, covering the whole process from planning and design to construction implementation, operation, and maintenance. The construction industry has entered a new era of digital, intelligent and information-oriented development [10]. As an important engine for the transformation and upgrading of the construction industry, it not only promotes the efficiency and quality of engineering projects but also facilitates energy conservation, emissions reduction, green construction and workplace safety. Project Cost Control (Earned Value Method)

$$CPI=\frac{EV}{AC} \quad (1)$$

Within the realm of smart construction, it is certainly an inevitable requirement that construction project management be digitally transformed. Traditional management models are often based on manual experience and paper-based documentation, which leads to low efficiency of information transmission and challenges in fine-tuning complex project implementation. Data, however, is at the heart of digital transformation. It builds up digital platforms and applies technological tools to facilitate real-time information sharing, dynamic tracking and intelligent analysis. Its spirit includes, not just the application of technology, but resolution and reorganization of organizational models (openness), management processes and even organization ecosystem.

The windfall that drives the digital transformation of construction project management mainly comes from national policies and the needs of industry development. In recent years, China has launched a series of policies and standards to set the development goals for promoting construction informatization and smart construction, thus laying an institutional foundation for industry transformation. With project scales stretching to unprecedented extents and engineering complexities compounding day by day, the pressures for effective collaboration and visible management from owners, contractors, and regulatory authorities push real-world implementation of digital transformation further.

In addition to external drivers like policy and demand, technological progress is an important catalyst. Emerging technologies, notably big data, the Internet of Things (IoT), cloud computing, artificial intelligence (AI), Building Information Modeling (BIM) and blockchain provide abundant tool support for rapid development and wide application in construction project management. These technologies offer the capability to retrieve, disseminate and analyze data from multiple origins, improve the visualisation and controllability of construction sites, as well as provide predictive decision-making support in project management. Green and low-carbon development also promotes the digitalization and intelligence of the industry, so that the construction industry can achieve economic benefits while considering social and environmental benefits ,showed in Figure 1 :

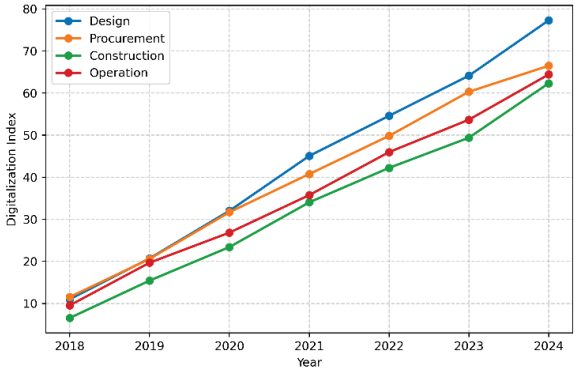

Figure 1 Digitalization Index trends across project phases

3. Practical Pathways for Digital Transformation in Construction Project Management

Digitization, or Digital transformation in construction project management is not just a simple substitution of something with a new technology toolkit. Its primary aim is to utilize digital technology to promote information integration throughout the project, intelligent control of construction processes, and efficient coordination between diverse stakeholders in order to fully optimize quality, schedule, cost and safety. Digital platforms and information integration represent the foundations of this process, while intelligent technologies democratizing construction management are the main enabler. Collaborative management and organizational transformation ensure the institutional support and management pathways that will effectively implement these three elements. They are interconnected, mutually reinforcing and together they make up the practical logic of digital transformation in construction project management.

3.1 Digital Platforms and Information Integration

Digital platforms are the infrastructure for change in contracting and project management. At the core, they are building linkages across the project lifecycle using information technology which is allowing them to store (the data), manage it and draw insights from one single pane of glass. Information silos that have incompatible data standards between design and construction, supervision, and operations inhibit this efficiency. Digital platforms address this by facilitating a common interface to the data and information exchange mechanism as standard across different entities. This provides for data interchangeability across the phases and all stakeholders, thus lending project management a systematic whole — holistic view of the process. Project Schedule Performance:

$$SPI=\frac{EV}{PV} \quad (2)$$

The integrated collaborative application of BIM technology and CIM platforms is one of the key solutions for information integration in construction practice. Building Information Modeling (BIM) allows the 3D visualization and presentation of design information, and aids in construction simulation analysis and schedule control. The combination of city-level data with data from the buildings themselves enables macro-level regional construction management, thus CIM platforms can help. This not only encourages the internal sharing of information within projects but also sets the stage for cross-project/cross-regional collaborative management.

The integration of cloud computing and big data technologies further enhances the information processing and analysis capabilities of the digital platform. In cloud storage and computing projects, real-time remote access and collaborative tasks are free from time and number limitations on the parties. Big data analytics continuously tracks and predicts trends of progress, cost, quality and safety data during construction stages, which provides scientific decision assistance for management. Such a data-driven management model is shifting construction project management from experience-based relying on intelligence and refined.

Integrating information is not only a technical problem, it also requires standards, specifications and institutional arrangements. The industry is still facing challenges like mismatched data interfaces and standards that make the platforms, well, not so interoperable with each other which increases the friction needed to share information. In the process of promoting digital platform construction, unified data standards and information management specifications should be adopted. Cross-departmental and cross-enterprise collaborative mechanisms should be established, complemented by enhanced information security systems. The integrated advancement of technology, standards and management systems is an important way to promote mutual transformation among digital platforms/information integration and share their capabilities, which shows that a solid foundation has been laid ergonomically for the relatively complete system of construction project management in the process of comprehensive digitalization. Risk Index in Construction Management :

$$R = P \times I \quad (3)$$

3.2 Empowering Construction Management with Intelligent Technologies

The widespread utilization of intelligent technologies offers potential for more detailed and dynamic management of construction processes, during the digital transformation of construction project management. Compared to traditional management methods based on manual experience, the intelligent technology realizes real-time collection, transmission and analysis of data, greatly improving the transparency and controllability of construction sites. By combining IoT, AI, and big data technologies, construction management is gradually entering a new phase of intelligent perception, prediction warning and scientific decision-making.

IoT technology can collect real-time progress information in construction sites monitoring important elements like safety, quality etc. Multidimensional data (such as temperature, humidity, vibration, and displacement) is collected by sensors, drones, or RFID devices and transmitted wirelessly to the management platform. This field data is used by managers for visualization and on-site monitoring of activities which helps to identify anomalies in time, enabling them to take corrective measures to reduce the risk of safety hazards and enhance the efficiency of construction.

AI-based decision-making support and risk warning. AI with machine-learning and deep-learning algorithms recognises hidden patterns in historical project data for trend analysis that help anticipate the probability of delay to construction schedules and cost overrun. Artificial intelligence technology also assists in image recognition and unmanned equipment distribution, using computer vision to automatically observe construction defects, and smart algorithms to smartly allocate resources by realizing automation and intelligence in construction management,as shown in Figure 2:

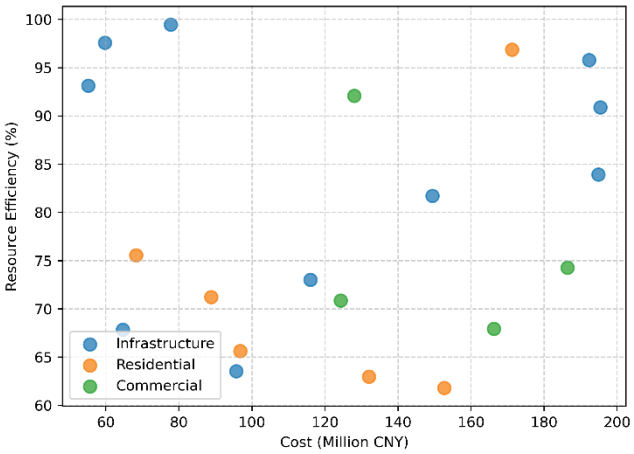

Figure 2 Resource efficiency vs cost over multiple projects

The application of big data analytics in the field of construction also enhances the scientificity of construction management. Using data from progress, cost and quality inspection views (big-table or low-level column format), managers act and evaluate the current situation of a project, get notice about future improvement problems in advance and prepare plans for improvements. Data mining and visualization technologies contribute to not only accurate planning but also vigorous support of refined control as well as long-term decision-making. The full value of intelligent technologies can only be released when they are integrated with management systems and personnel capabilities, so effectively implementing technology is worthy of attention. In the process of promoting intelligent transformation in construction management, we should pay attention to technical training and organizational structure optimization so that intelligent technologies are integrated into all stages of construction management process, continue to create lasting benefits for enterprises. Resource Allocation Optimization (simplified)

$$\min Z = \sum_{i=1}^{n} c_i x_i \quad \text{s.t.} \quad \sum_{i=1}^{n} a_{ij} x_i \leq b_j \quad (4)$$

3.3 Collaborative Management and Organizational Transformation

Construction projects are multistage processes that cause multiple stakeholders (owners, designers, contractors, supervisors and suppliers) to be all involved in it. Old management models can lead to

solutions characterised by ineffective communication between stakeholders, high coordination costs, delays in decision-making and waste of valuable resources. Digital transformation provides new opportunities for collaboration management tools and platforms. Unified information systems enable collaboration via real-time communications contributing to shared data resources across entities. This right kind of data-driven collaboration management model improves efficiency at all stages across the project lifecycle, reduces rework and disputes while providing a seamless delivery to construction.

The impact of Industry 4.0 transformation is particularly evident in the construction domain where it comes on top of very advanced project management paradigms including EPC (Engineering, Procurement and Construction), IPD (Integrated Project Delivery) etc which increasingly use digital technologies. Design and construction teams can use BIM collaboration platforms to share plans, while dynamically updating changes as work proceeds in real time preventing hand offs that can distort information due to delays. With digital management systems, owners can immediately check the status of construction progress and quality status for more proactive and informed decision-making. This kind of collaboration enhances the transparency and controllability in project governance, as well as smoother integration on workflows.

With its collaborative management, it will also raise new demands on organizational structure. In this digital age, management methods reliant upon hierarchy and compartmentalization are more than ever antiquated for project operations. Digital transformation requires organizations to become more horizontal and agile — ones that can work seamlessly across departments and conclusions. Management processes also have to evolve well — with more holistic, cross-threaded trajectories enabled by traditional sdigital forms of multithreaded thinking that can quickly adapt in a digital environment where these project requirements constantly shift.

As facilitators of change, talent development and cultural transformation are key players in collaborative management. The fierce need to adapt them to the realities of digital transformation is not simply applicable only at digital tool or product level but also essential at people-level with those individuals equipped with interdisciplinary knowledge, digital literacy and innovation capabilities. Enterprise culture needs to shift from experience to data driven and collaborative, promoting knowledge sharing and cross boundary collaboration. Collaborative management can only be achieved by synergistic technology-organization-culture integration, which further leads construction project management from “digitalization” to “intelligentization.”

4. Challenges and Countermeasures in Digital Transformation

However, despite the trend of inevitable development to digital transformation in construction project management, there are still many problems need to solved based on practice. The lack of an industry-wide standard system deprives this information from being fully shared and used between different platforms and systems, resulting in isolated pockets of information and incompatible interfaces. At the same time, companies wishing to digitalize their operations were forced to make large upfront capital investments in the hardware needed for worksites as well as costs associated with setting up and maintaining a platform which became major financial burdens for many small and medium-sized construction firms and prevented widespread adoption. As a result, due to the relatively weak information technology foundation of the construction industry and limited understanding of digital transformation of some enterprises, practical application effect is not high.

These issues are especially prevalent with data security and privacy protection. With the growing use of cloud computing and IoT platforms in project management, substantial amounts of sensitive data must be stored and sent across networks. Without strong security measures, this poses a significant risk of data breaches and security vulnerabilities. For many companies, their IT capabilities and digital maturity are at different levels with a severe gap leading to the digital divide within the industry with an impasse that prevents from coming out of this into a unified collaborative digital ecosystem. BIM Data Integration Metric

$$DI=\frac{\sum_{i=1}^{n} w_i d_i}{\sum_{i=1}^{n} w_i} \quad (5)$$

The talent shortages represent another bottleneck to digital transformation in construction project management. This would require human resources with different capabilities, and not just IT people but hybrid professionals that have engineering management expertise, as well as digital capabilities. The talent pool of the construction sector is still mostly conventional, and only few in the industry have cross-disciplinarian skill set. The shortage hampers the efficiency of digital technologies used in corporate management.

A coordinated approach across policy, technology and organizational dimensions is needed to mitigate these challenges. Establishing unified data interfaces and information exchange protocols is also critically important to enhance interoperability across platforms, which will require the acceleration of industry standards development. Furthermore, governments should further increase policy and finance support, offer monetary subsidies and technical assistance to reduce transformation obstacles for small- and medium-sized enterprises. At the technological level, good data security frameworks need to be established to enhance information systems safety and stability. Enterprise enterprises must establish more extensive and cohesive multi-disciplinary talent bases to enhance the cooperation between universities and industries, increase training diversity, and improve the yield of recruitment, improving the foundation of human capital for digital transformation. Only by combining refined standards, policy support, technical security and talent supply to promote the digital transformation of construction project management can achieve sustainable development.

5. Conclusion

Under the background of intelligent construction, it is an inevitable choice to promote high-quality development of the industry through digital transformation in construction project management. In this context, this paper attempts to study the essence of smart construction and digital transformation in construction project management together with its driving factors. It lays out a pragmatic roadmap hinged on digital platforms & information integration, rooted by intelligent technologies powering construction management, and protected via collaborative management and organizational transformation. In addition, it discusses the main problems faced in the transformation and their measures. Studies show that digital tranformation can improve the informatization level and management efficiency of construction projects, safety control, cost management, resource allocation and more, providing new impetus for green intelligent sustainable development of the industry.

As emerging technologies such as AI, blockchain and the metaverse reach maturity stages and their practical applications mature - construction project management will move towards a new era of intelligence, automation, smarter buildings and smart operations. Digital transformation represents not just a technological innovation process, but rather an organizational change and conceptual renewal of systematic results that need to be tackled through consensus building and collaborative progression between governments, industries, and enterprises. Smart construction, after all, can only take place by considering the collaborative interaction between technologies, systems, talent and culture.

References

[1] Wenqiang Y , Xiangyu B , Lin Z L .A digital twin framework for large comprehensive ports and a case study of Qingdao Port[J].The International Journal of Advanced Manufacturing Technology, 2024, 131(11):5571-5588.DOI:10.1007/s00170-022-10625-1.

[2] Ostroukh A V , Kuftinova N G , Gaevskii V V ,et al.Digital Transformation of Enterprises Using a Low-Code Platform[J].Russian Engineering Research, 2022, 42(11):1203-1206.DOI:10.3103/S1068798X22110193.

[3] Daly S .Design heuristics in engineering concept generation[J].Journal of Engineering Education, 2012, 101(4):601-629.DOI:10.1002/j.2168-9830.2012.tb01121.x.

[4] Ferrer L , Dale J M , Karp P D .A systematic study of genome context methods: calibration, normalization and combination[J].Bmc Bioinformatics, 2010, 11(1):493-493.DOI:10.1186/1471-2105-11-493.

[5] Nishi T , Matsuda M , Hasegawa M ,et al.Automatic Construction of Virtual Supply Chain as Multi-Agent System Using Enterprise E-Catalogues[J].International Journal of Automation Technology, 2020, 14(5):713-722.DOI:10.20965/ijat.2020.p0713.

[6] Lin H , You L , Hu C ,et al.Prospect of Geo-Knowledge Engineering in the Era of Spatio-Temporal Big Data[J].Wuhan Daxue Xuebao (Xinxi Kexue Ban)/Geomatics and Information Science of Wuhan University, 2018, 43(12):2205-2211.DOI:10.13203/j.whugis20180318.

[7] Junker B H , Klukas C , Schreiber F .VANTED: A system for advanced data analysis and visualization in the context of biological networks[J].Bmc Bioinformatics, 2006, 7(1):109-109. DOI:10.1186/1471-2105-7-109.

[8] Wenzhi Z , Zecheng W , Menjin C ,et al.Formation Mechanism of the High-quality Upper Paleozoic Natural Gas Reservoirs in the Ordos Basin[J]. Journal of Geology: English Edition, 2005, 79(6):13.DOI:10.1111/j.1755-6724.2005.tb00939.x.

[9] Hédi Soula,Céline Robardet, Perrin F ,et al.Modeling the emergence of multi-protein dynamic structures by principles of self-organization through the use of 3DSpi, a multi-agent-based software[J].BMC Bioinformatics, 2005, 6(1):228.DOI:10.1186/1471-2105-6-228.

[10] Lu Y , Yang H , Ma L ,et al.Application of Pb isotopic tracing technique to constraining the source of Pb in the West Lake Longjing tea[J] . Journal of Geochemistry (English), 2011, 30(4):9. DOI:10.1007/s11631-011-0539-x.