BIM-based Intelligent Construction Enterprise System Framework

Jingkai Wang [1,a*], Xingyuan Zhao [1,b], Shuchen Huang [2,c], Tao Huang [2,d], Fangyi Xie [3,e], Zhibin Li [3,f]

[1] China Energy Construction Digital Technology Group Co., Ltd. Beijing, China
[2] Higher Institution Engineering Research Center of Structural Engineering and NewMaterials, BUCEA, Beijing, China
[3] Beijing North-Star Digital Remote Sensing Technology Co., Ltd. Beijing, China

* Corresponding author: [a] jkwang4536@ceec.net.cn;
[b] e-mail: xyzhao3215@ceec.net.cn; [c] e-mail: wwwhuangshu@163.com;
[d] e-mail: huangtao1306@163.com; [e] e-mail: fyxie003x@ceec.net.cn;
[f] e-mail: zbli1679@ceec.net.cn

Abstract. Digital technologies are leveraged in intelligent construction to improve efficiency and quality in engineering projects. In this study, BIM-based intelligent construction is investigated, with a focus on transforming traditional workflows in the energy and construction sectors. An intelligent construction framework for the China Energy Engineering Corporation, termed "Two Main Lines, Three Dimensions, Four Stages," is proposed. This framework includes two main lines—virtual and physical construction—and three dimensions of time, data, and technology, covering four lifecycle stages: intelligent design, intelligent production, intelligent construction, and intelligent operation. It provides a theoretical foundation for advancing digital transformation within the corporation.

Keywords: intelligent construction; system framework; time dimension; data dimension; technology dimension

1 Introduction

The arrival of the fourth industrial revolution has accelerated the industrialization of the construction industry, driving rapid advancements in digital and intelligent technologies. Intelligent construction is now considered the future direction of the industry, evolving from the concept of 'digital construction' 12. In general, intelligent construction is a highly integrated and collaborative construction system that utilizes technologies such as Building Information Modeling (BIM), the Internet of Things (IoT), artificial intelligence (AI), cloud computing, and big data, enabling real-time adaptation to changing needs.

G. Zhao et al. (eds.), *Proceedings of the 2024 6th International Conference on Civil Architecture and Urban Engineering (ICCAUE 2024)*, Advances in Engineering Research 262,
https://doi.org/10.2991/978-94-6463-688-8_25

The emergence of intelligent construction has led to the rapid integration and development of related technologies, which are applied in the industry to make design, production, construction, and management more informative and intelligent, thereby driving a new wave of manufacturing revolution and ushering in a new stage of high-quality development in the Chinese construction industry 3. In this context, China has made remarkable achievements globally, especially in high-difficulty engineering fields 45. Meanwhile, information technology in China is advancing rapidly, with digitalization, networking, and intelligence driving innovation and transformation across all industries. However, the current understanding of intelligent construction is not consistent, and challenges remain in integrating it with enterprise production 6. As intelligent construction is getting more and more widespread attention, some scholars try to explain its concept. By reviewing the research literature related to intelligent construction, the definitions provided by some domestic scholars are summarized in 0

Table 1. Concepts related to intelligent construction

Serial number	**Author**	**Definition**
1	Ding, L.Y. 7	Intelligent construction builds a knowledge-driven construction model for the entire project life cycle by integrating artificial intelligence and industrialized construction technology, big data analysis, intelligent algorithms, and knowledge automation.
2	Xiao, X.W. 8	Intelligent construction takes perception technology as its core, encompassing the entire process from project initiation, design, construction, to management, and achieves fine control of construction activities and intelligent process operations through an information technology platform and robots with complementary functions.
3	Qian, Q.H. 9	Intelligent construction promotes the development of engineering construction towards digitization and intelligence through the in-depth application of emerging information technologies such as big data, artificial intelligence, the Internet of Things, and 5G, and realizes reduced manpower and unmanned operations to ensure the high quality and safety of projects.
4	Yang, Z.Q. 10	Intelligent construction integrates industrialized and standardized construction methods through the application of BIM technology, intelligent construction sites, and intelligent equipment to achieve the collaborative operation of virtual and real environments, thereby enhancing project construction efficiency and the quality of finished products.

5	Mao, Z.B 11	Intelligent construction integrates industrialized and standardized construction methods through the application of BIM technology, intelligent construction sites, and intelligent equipment to achieve collaborative operation of virtual and real elements, enhancing project construction efficiency and the quality of finished products.
6	Fan, Q.X. et al 12	Intelligent construction refers to the comprehensive integration of various technologies and knowledge, such as sensing, communication, data analysis, construction processes, and project management, with the goal of achieving intelligent control over construction safety, quality, environmental sustainability, schedule, and cost.
7	Mao, C. et al 13	Intelligent construction promotes the advancement of the entire industrial chain by deeply integrating information technology with industrialization. It leverages new technologies to enhance the efficient allocation of production factors, ensure the seamless flow of data, and achieve information integration, business synergy, and maximization of resource value.
8	You, Z.J et al 14	Intelligent construction optimizes life cycle management of engineering projects through the integration of intelligent technologies, enhancing the autonomy of construction systems while reducing dependence on manual labor to achieve quality improvements and sustainable development.
9	Chen, K et al 15	Intelligent construction aims to transform the entire construction industry by integrating intelligent technologies throughout all stages, including design, production, construction, and operation and maintenance. This transformation promotes the development of innovative business models and facilitates a comprehensive shift towards increased efficiency and sustainability.
10	DeWit, A. 16	Intelligent construction aims to reduce costs, enhance accuracy, minimize resource waste, and improve the resilience and sustainability of buildings by leveraging innovative robotic technologies.

Referring to the definitions of intelligent construction by various scholars and considering the enterprise's own production context, this paper analyzes how intelligent construction can be utilized to guide the digital transformation of different business segments in energy construction. It proposes a system framework based on BIM technology across multiple scenarios and provides a definition of intelligent construction applicable to enterprise transformation, along with application cases for each business scenario.

2 Methods

The scenario application of the intelligent construction system developed by China Energy Engineering Corporation (CEEC) encompasses intelligent design, production, construction, and operation and maintenance. Grounded in fundamental concepts, definitions, and standard specifications, and incorporating technologies such as Building Information Modeling (BIM), big data, cloud computing, artificial intelligence, and the Internet of Things (IoT), the system framework for intelligent construction presented in this paper is illustrated in 0

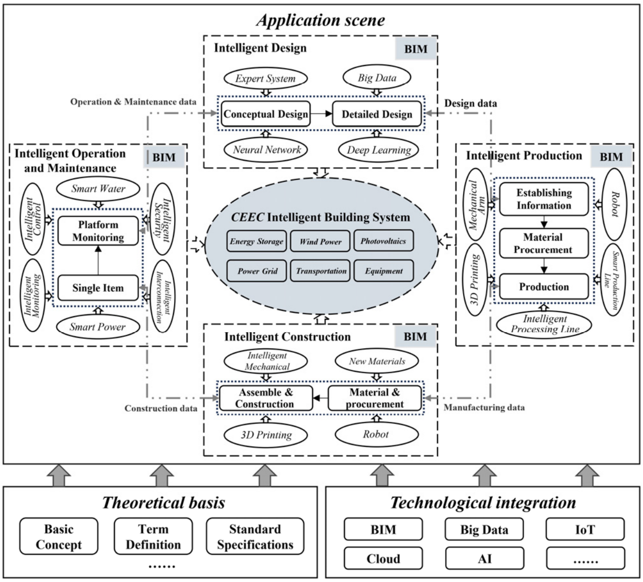

Fig. 1. Intelligent construction system framework of CEEC

In the design phase, intelligent design data is provided to the manufacturing unit, and the data and information from manufacturing are transferred to the construction unit through intelligent mechanical processing and production. In the intelligent construction phase, various intelligent machines and new materials, such as 3D printing and robots, are utilized to complete the material and equipment procurement, installation, and construction processes. Finally, the data and information generated throughout the entire production process are consolidated in the intelligent operation and maintenance system, which enables real-time monitoring of production and construction, intelligent interconnection, intelligent inspection, and post-maintenance. Additionally, the data generated during the operation and maintenance phase can be fed back to the design phase, creating a bidirectional data flow between design and operation and maintenance.

Based on Hall's 'three-dimensional structure' model, we comprehensively analyze the detailed characteristics of the BIM-based intelligent construction system framework and further deduce its evolution to form a theoretical model applicable to this study, as shown in 0

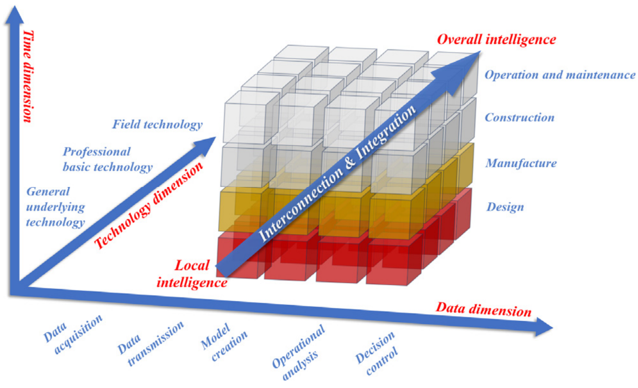

Fig. 2. CEEC Intelligent Construction Theory 3D Structural Model

In the time dimension, the intelligent construction theoretical framework diagram illustrates the time dimension of intelligent construction throughout the entire life cycle of engineering and construction. From the design stage to the production stage, the construction stage, and finally the operation and maintenance stage, the entire construction process is represented linearly over time, highlighting the application and role of intelligent construction technology at different stages.

In terms of the data dimension, the theoretical framework diagram of intelligent construction highlights the significance of data in the process of intelligent construction. Data plays a crucial role in intelligent design, production, construction, and operation and maintenance, spanning the entire life cycle of each business segment of CEEC, from design, production, and construction to final delivery and operation and maintenance. The data system adopts a 'top-down' data description model, implementing a data-centric approach that defines the organizational structure, management processes, and work standards, while also regulating data development. It promotes data sharing and value extraction, establishes data governance capabilities, enables the sharing of data resources across industries and sectors, and integrates and consolidates information resources to fully exploit the potential value of data, ultimately maximizing data assets.

In the technical dimension, the theoretical framework diagram of intelligent construction illustrates the application of multiple technologies, including BIM, big data, cloud computing, artificial intelligence, and the Internet of Things. These technologies are utilized at different stages, such as engineering software for whole-industry chain integration, engineering IoT for intelligent engineering, intelligent engineering machinery for human-machine collaboration, and engineering big data for intelligent decision-making. These field-specific technologies support the entire engineering and construction process, encompassing all elements, facilitating collaboration among all participants, and driving industrial transformation. Through the analysis of the time, data, and technology dimensions, the theoretical framework diagram of intelligent construction clearly demonstrates the application and role of intelligent construction technology throughout the entire life cycle of engineering and construction, as well as the critical importance of data and technology within it.

CEEC views intelligent construction as a production approach that achieves dynamic configuration through efficient collaboration between human resources and intelligent tools and equipment, integrating design and management to transform and upgrade the entire life cycle of engineering projects, from design to operation and maintenance. By integrating advanced technologies and innovative methods such as BIM, this approach aims to enhance efficiency, quality, and sustainability across CEEC's domains, including power generation, new energy development, engineering construction, and equipment manufacturing. Through the interconnection of the three dimensions of time, data, and technology, this approach integrates localized intelligence into a comprehensive intelligent system, achieving digitally-driven, high-efficiency collaboration and integration across CEEC's business sectors, such as energy storage, power grids, housing construction, wind power, photovoltaics, energy, municipal projects, and transportation. Ultimately, it enables the delivery of intelligent engineering products and services to end-users.

In summary, compared with traditional intelligent construction system frameworks, the framework proposed in this paper offers significant advantages. By integrating the three dimensions of time, data, and technology, it enables dynamic management and bidirectional data feedback throughout the entire project life cycle, thereby addressing the issue of data isolation at various stages in traditional frameworks. Additionally, the integration of technologies such as machine learning and big data analysis facilitates intelligent scheduling, risk prediction, and optimization design. Unlike traditional frameworks that focus on a single aspect, this framework emphasizes closed-loop management to proactively identify and optimize problems in real time. Moreover, the incorporation of multi-source data fusion and self-learning capabilities allows the framework to continuously accumulate experience, enhancing the adaptability and flexibility of complex projects, and significantly improving construction efficiency, resource utilization, and intelligent management.

3 Results & Discussion

In the theoretical framework of intelligent construction proposed in this paper, BIM technology serves as the core support, extending across all stages of design, production, construction, and operation and maintenance. By integrating intelligent systems with digital technologies, this framework enables comprehensive management and optimization throughout the entire building life cycle. The following sections will provide a detailed explanation of the specific applications and outcomes of the framework in each of the four stages: intelligent design, intelligent production, intelligent construction, and intelligent operation and maintenance.

3.1 Intelligent Design

Intelligent design based on BIM technology focuses on industrial product demand, integrating all disciplines and facilitating collaboration among all stakeholders. BIM models are used to pre-assess core construction, operation, and maintenance issues during the design stage, enabling intelligent and parametric simulation throughout the project's life cycle. This process ensures efficient collaboration and iterative optimization of design, procurement, production, construction, and operation and maintenance, thereby mitigating engineering risks, enhancing cost-effectiveness, reducing design changes, and ultimately delivering a high-quality, cost-effective, feasible, and easy-to-maintain product solution that meets project requirements.

China Energy Engineering Group Shanxi Electric Power Engineering Company, a subsidiary of CEEC, has developed and piloted the 'Substation Monitoring Information Point Table Intelligent Design Software V1.0' in projects. The software is built on a new-generation digital intelligent design platform for substation secondary systems, adopting modular and structural modeling concepts to create a template library and matching rules library for monitoring information point tables for different project types. The software enables integration and interaction between operation and maintenance data and 3D digital design data, ensuring standardization and unification of substation monitoring information point lists from the design stage. It addresses issues such as lengthy work time, non-standardized products, and quality assurance challenges in the manual compilation of substation monitoring information point lists. This advancement significantly improves the efficiency of compiling and auditing substation monitoring system information point lists.

3.2 Intelligent Production

Intelligent production based on BIM focuses on using intelligent systems to efficiently coordinate and optimize manufacturing resources, including raw materials, production equipment, and processes. BIM technology plays a critical role in this process by providing accurate product information and data models, allowing the intelligent production system to better understand production requirements, optimize processes, and ultimately achieve a high-quality, high-efficiency industrial manufacturing model.

China Gezhouba Cement Company’s Laohekou Company, a subsidiary of CEEC, has implemented a digital mine project at the chert mine by combining automation technology with on-site monitoring. This has enabled visual production management of the mining area and production line, with the limestone crushing and belt conveying systems largely achieving intelligent processing, reducing the labor intensity of post operators, and improving production efficiency.

The fully automated intelligent crane project at China Gezhouba Cement Company’s Yicheng Company joint storage depot introduces parametric and modular design from the technical dimension, utilizing computer-aided design and simulation technology, sensing, measurement and control, pattern recognition, and automatic control technologies to achieve fully automated crane operations in the cement plant's joint storage depot.

3.3 Intelligent Construction

Intelligent construction based on BIM technology is process-centered, integrating online virtual and offline physical construction, with simulation prior to implementation. The virtual phase includes detailed design, scheduling, procurement, and simulation, while the physical phase focuses on resource supply, construction, acceptance, and on-site measures. Digital and physical production lines mirror each other to achieve accurate and efficient digital twin lean construction.

The intelligent project management of CEEC is embodied in the overall solution of Smart Site, which is a new information management approach that utilizes advanced digitalization to support comprehensive perception of people and objects, interoperability of work, collaborative information sharing, scientific decision-making analysis, and intelligent risk pre-control. The technological dimension of the framework emphasizes the integration of various technologies to optimize the construction process. This includes the use of new construction materials and intelligent machinery and equipment. Intelligent equipment, such as smart helmets and smart bracelets, serves as new intelligent terminal products characterized by intelligent sensing, interconnection, and human-computer interaction. Intelligent machinery, such as smart excavators, utilizes multi-information fusion—such as sensing, detection, vision, and satellite data—to provide environmental perception and operational planning and decision-making capabilities.

In the project construction process, several subsidiaries in the energy industry, such as China Energy Engineering Group Tianjin Electric Power Construction Company of CEEC, have applied the company's self-developed intelligent site management platform in the field of new energy. This platform facilitates modular and customized development and application for the collection of information related to 'man, machine, material, method, and environment,' establishing eight major management modules: project information, progress, quality, safety, environment, personnel, machinery, and digital site. It forms a project digital integration platform that includes a labor real-name system, intelligent video monitoring system, and safety inspection system, as illustrated in 0

.

Fig. 3. Intelligent site platform

3.4 Intelligent Operation and Maintenance

Intelligent operation and maintenance based on BIM is a mechanism designed to identify and analyze the causes of problems and anomalies encountered throughout the project's life cycle. When operational issues or abnormal activities occur, they are detected quickly, and the root causes are analyzed intelligently, enabling early intervention by the operation and maintenance staff to minimize potential damage. If system problems or anomalies arise, it is crucial to accurately determine their location and underlying factors. The system should also adopt preventive measures during operation to anticipate potential issues and reduce their occurrence or swiftly address faults.

Gezhouba Group Eco-Environmental Protection Company of CEEC has implemented intelligent operation in water plants, creating a 'smart water plant' to integrate and develop the digital industry, as shown in Figure 4. For the third phase of the Jingu Wastewater Treatment Plant, the framework incorporates the technical dimensions of the Internet, big data, artificial intelligence, and other modern technologies to build a multi-dimensional dynamic model for real-time diagnostics and state prediction. The introduction of this intelligent model has completely transformed the traditional sewage treatment plant operation, addressing issues such as increased energy consumption and chemical waste caused by experience-based control. Compared to traditional sewage treatment plants, the third-phase project has reduced power consumption per tonne of water by over 10% and chemical usage by more than 15%, resulting in annual savings of over 6 million kWh of electricity and more than 5 million yuan in pharmaceutical costs.

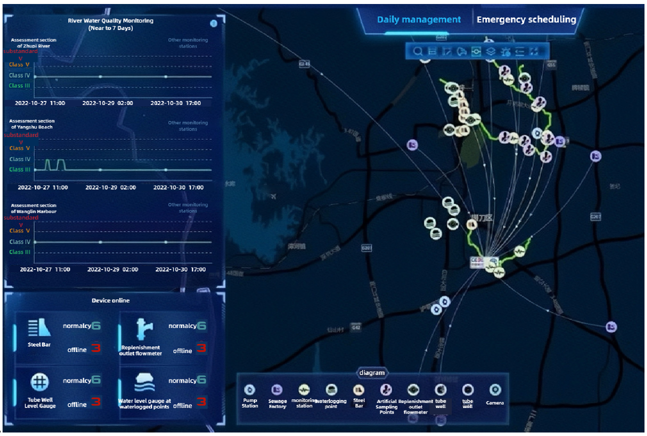

Fig. 4. Intelligent water operation and maintenance system

3.5 Limitation analysis and prospect

There are several challenges in implementing the intelligent construction framework. First, the high infrastructure costs required to deploy the framework pose significant pressure on small and medium-sized enterprises (SMEs). Second, interoperability and data standardization issues among different technologies (BIM, AI, IoT, etc.) increase the complexity of system integration. Additionally, the demands of real-time monitoring and data processing require stable sensor networks and robust data analysis capabilities. Finally, the successful implementation of the framework depends on staff training and adaptation to new skills, with skill gaps and resistance to change potentially impacting effectiveness.

Future research should focus on the deep integration of the framework with emerging technologies. Simultaneously, efforts should be made to further enhance predictive algorithms and data analysis capabilities, while establishing relevant standards to improve system interoperability and integration efficiency.

4 Conclusions

This paper explains the concept of intelligent construction and combines the above concepts to propose an intelligent construction system framework and technology integration approach based on the multi-scenario dimensions of BIM technology. It refines the definition of intelligent construction applicable to enterprise transformation. Using Hall's 'three-dimensional structure' model, the detailed characteristics of the framework are analyzed, and a theoretical model applicable to this study is proposed. The comprehensive application of CEEC's intelligent transformation under the guidance of the current intelligent construction enterprise framework is presented. The main conclusions are as follows:

- Intelligent construction is a new construction model based on BIM, IoT, AI, cloud computing, big data, and other technologies, aiming to optimize the entire life cycle of a project. The system framework proposed in this paper highlights the importance of integrating smart construction with BIM technology, emphasizing the data-driven construction approach and the role of BIM technology in enhancing efficiency and quality.
- The three dimensions in the theoretical model proposed in this paper are the time dimension, data dimension, and technology dimension. These dimensions respectively represent the time span of intelligent construction throughout the entire life cycle of engineering and construction, the critical stages of bidirectional data flow in the intelligent construction process, and the comprehensive use of BIM and other intelligent technologies during intelligent construction. The theoretical model provides a hierarchical division of the system framework implementation process, facilitating the development from localized intelligence to overall intelligence.
- This paper focuses on the four main stages of intelligent design, intelligent production, intelligent construction, and intelligent operation and maintenance within the current system framework. It introduces representative engineering projects during

the transformation and upgrading of various business segments of CEEC and summarizes the theoretical basis of the system framework corresponding to each project, providing theoretical guidance for practitioners and decision-makers in related industries.

Acknowledgment

This work was supported by the Major Scientific and Technological Project of China Energy Engineering Corporation Limited (Grant No. CEEC2021-KJZX-07). The authors would like to express their gratitude to China Energy Engineering Corporation Limited for providing the funding and support that made this research possible.

References

1. Naji, K.K., Gunduz, M., Alhenzab, F.H., Al-Hababi, H. and Al-Qahtani, A.H. (2024) A Systematic Review of the Digital Transformation of the Building Construction Industry. IEEE Access, 12: 31461–31487.
2. Musarat, M.A., Hameed, N., Altaf, M., Alaloul, W.S., Salaheen, M.A. and Alawag, A.M. (2021) Digital Transformation of the Construction Industry: A Review. In: 2021 International Conference on Decision Aid Sciences and Application (DASA). Sakheer, Bahrain. pp. 897-902.
3. Wang, B., Chen, J.R., Liao, F.W. and Ao, Y.B. (2023) Paths and Policies for Green and Low Carbon Transformation of Construction Industry under the Background of Intelligent Construction. Science and Technology Herald, (05): 60–68.
4. Lin, M., Wang, Q.E., Wang, M.J. and Li, J.G. (2018) Exploration and practice of intelligent construction for Hong Kong-Zhuhai-Macao Bridge island-tunnel project. Science and Technology Progress and Countermeasures, (24): 81–85.
5. Wu, X.G., Liu, J., Chen, H.Y., Cao, Y. and Qin, Y.W. (2024) Feasibility study on the application of intelligent construction technology for large-span steel truss bridge. Civil Engineering Information Technology, (02): 12–17.
6. Liu, Z.S., Sun, X.T. and Shi, G.L. (2021) A review on the application of intelligent construction in civil engineering construction. Construction Technology (In English and Chinese), (13): 40–53.
7. Ding, L.Y. (2019) Reflections on the cultivation of innovative engineering and technology talents for intelligent construction. Research on Higher Engineering Education, (05): 1–4+29.
8. Xiao, X.W. (2022) Smart construction: what, why, what and how. Construction Business Management, (12): 29–31.
9. Qian, Q.H. (2022) Some thoughts on green development and intelligent construction. Building Technology, (07): 951–952.
10. Yang, Z.Q. (2022) From BIM to Intelligent Construction. Construction Enterprise Management, (07): 46–47.
11. Mao, Z.B. (2019) Intelligent construction determines the future of the construction industry. Architecture, (16): 22–24.
12. Fan, Q.X., Lin, P., Wei, P.C., Ning, Z.Y. and Li, G. (2021) Closed-loop control theory for intelligent construction. Journal of Tsinghua University (Natural Science), (07): 660–670.

13. Mao, C. and Pang, Y.Y. (2020) Theoretical framework and core logic construction of intelligent construction. Journal of Engineering Management, (05): 1–6.
14. You, Z.J., Zheng, L.Q. and Feng, L.J. (2021) Fundamental Theory and Architecture of Intelligent Construction Systems. Journal of Civil Engineering and Management, (02): 105–111+118.
15. Chen, K., Zhang, Y.H., Guo, F.Y. and Wang, H.D. (2023) Research on the new industry of construction industry under the background of intelligent construction. Science and Industry, (12): 131–135.
16. DeWit, A. (2015) Komatsu, smart construction, creative destruction, and Japan's robot revolution. The Asia-Pacific Journal, 13(5): 2.