

Challenges and Development Countermeasures of Intelligent Construction to the Traditional Construction Industry

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Abstract. As the basic pillar industry of the national economy, the construction industry has a long-standing structural contradiction between the continuous expansion of output value and the slow improvement of production efficiency. Intelligent construction relies on the deep integration of digital technology and the construction industry to reconstruct the whole life cycle of the construction industry chain and systematically transform the traditional construction process from design, production, construction and operation and maintenance. However, in the process of landing domestic industries, it still faces multiple practical obstacles such as external dependence on core technologies, lack of unified data standards, insufficient supply of digital talents, and high costs for early transformation. Based on the theoretical framework of the five stages of the whole life cycle of intelligent construction, this article sorts out the application logic of the four core technologies of Building Information Modeling (BIM), the Internet of Things (IoT), intelligent engineering machinery and engineering big data, compares the differences in the development path of European and American construction 4.0, Japanese construction robot industrialization and domestic intelligent construction industry development, quantitatively analyzes the transformation results of intelligent construction on the four major business links of the traditional construction industry, systematically identifies the core bottlenecks of current industrial transformation, and puts forward a hierarchical industrial development path in three time dimensions: short-term, medium-term and long-term. The findings provide theoretical reference and practical basis for local housing and construction departments to formulate intelligent construction support policies and the digital transformation of construction enterprises.

Keywords: Intelligent Construction, Building Information Modeling, Construction Industrialization

1. Introduction

Thanks to the continuous advancement of urbanization, the total output value of the domestic construction industry has maintained the first place in the world for many years. In 2024, the total output value of the national construction industry exceeded 33 trillion yuan, and the industry absorbed more than 50 million people, which plays an irreplaceable supporting role in stabilizing employment, improving urban and rural infrastructure, and driving real economic growth [1].

Behind the huge industrial scale, the industry has been deeply trapped in the efficiency paradox of "high output value and low efficiency" for a long time. The labor productivity is only one-third of the average of the domestic manufacturing industry. The production mode based on on-site pouring has brought about excessive emissions of construction waste, frequent construction safety accidents, failure of project cost control and other intractable diseases, which have formed a significant conflict with the national strategic goal of carbon peak carbon neutrality [2]. Carbon emissions in the construction industry account for about 40% of the total terminal carbon emissions in the country. The traditional construction mode has high resource consumption intensity and concentrated pollution emissions. The rough construction system relying on manual experience cannot complete the whole life cycle low-carbon control, and the digital transformation of the industry is imminent [3]. In 2017, the Ministry of Housing and Construction put forward the development direction of intelligent construction for the first time. Subsequently, a number of top-level policy documents were issued to promote the coordinated implementation of digital technology and construction industrialization. Intelligent construction has gradually become the core path to solve the dual pressure of industry efficiency and low carbon [4].

In the process of practical implementation of digital technology intervention in engineering construction, the academic community and the industry have not yet formed a unified consensus. There are still many practical problems to be clarified in the mechanism of intelligent construction in transforming the traditional construction model and the resistance to transformation. The existing research focuses more on the analysis of the application effect of a single technology scenario, or the case summary of a single-regional pilot project. There is a lack of quantitative analysis of systematic change that covers the whole industrial chain and stages. Nor are there complete arguments on core issues such as the extent to which intelligent construction can solve the inherent shortcomings of the traditional construction industry, how various technologies can work together to reshape the whole process of construction, and the differentiated obstacles facing the transformation of different market entities. Based on the above research gaps, this paper sorts out the complete technical system of intelligent construction and the five-stage full-life cycle coordination framework, compares the differences in industrial development practices of mainstream countries in the world, quantitatively analyzes the subversive changes of intelligent construction to the traditional construction mode in the four dimensions of design, prefabricated production, on-site construction and project management, identifies the four development bottlenecks of technology, standards, talents and costs based on the domestic industrial reality, and gives implementable optimization countermeasures in stages in combination with the industrial development cycle. Finally, it summarizes the core conclusions and points out the limitations of this article to provide direction for the subsequent empirical studies.

2. The technical system and the whole life cycle framework of intelligent construction

2.1. Core key technologies

Intelligent construction is not a simple superposition of a single digital tool, but a complete technical system formed by the coupling of four types of underlying technologies, covering the whole process of the project from early planning to late demolition and operation and maintenance. Different technologies undertake differentiated functional positioning, and jointly realize the digitalization, automation, visualization of the whole construction process [2]. Engineering software takes Building Information Modeling as the core carrier. Relying on the three-dimensional digital model to integrate multi-dimensional data such as architectural geometric parameters, material attributes,

equipment performance, cost information, etc., it breaks the limitations of the separation of professional information in traditional two-dimensional drawings, and realizes multi-professional collaborative design, automatic collision verification, and accurate calculation of engineering volume. It is the underlying carrier of intelligent construction of all data flow and the basic tool for the digital transformation of the construction industry at home and abroad [5]. The Internet of Things (IoT) technology for intelligent construction sites relies on-site sensors, intelligent safety helmets, environmental monitoring terminals, tower machine monitoring equipment and other hardware to collect dynamic data such as personnel positioning, mechanical operation, dust noise, structural settlement and so on at the construction site in real time, complete the real-time mapping between physical construction sites and digital models, realize dynamic perception and automatic risk early warning in the whole process of construction, and make up for the shortcomings of manual inspection and control of traditional construction sites [6]. Intelligent engineering machinery includes construction robots, automated prefabricated production lines, unmanned mapping drones, automatic rebar processing equipment and other automated equipment, replacing traditional high-strength and high-risk manual operations, reducing on-site manpower dependence, and improving construction standardization and operation accuracy. Japan, Germany and other developed countries have realized the large-scale commercialization of multiple categories of construction robots [7]. As a data hub for the whole process, engineering big data integrates Building Information Modeling (BIM) static model data, real-time dynamic monitoring data of the IoT, enterprise historical project cost construction database, and supply chain material information. It enables project progress prediction, cost deviation warning, security risk identification, operation and maintenance energy consumption optimization through machine learning algorithms. It also transforms the traditional decision-making mode that relies on the personal experience of project managers into a data-driven quantitative decision-making system [8].

The four types of technologies have clear synergy: BIM provides a static digital base, the IoT continuously supplements on-site dynamic data, intelligent machinery undertakes digital instructions to complete physical construction operations, and engineering big data integrates all-dimensional information output to optimize decision-making schemes. The four form a closed loop of data collection, storage, operation and execution, which together constitute the underlying technical support system of intelligent construction.

2.2. Five-stage coordination of the whole life cycle

The core feature distinguishing intelligent construction from the traditional segmented model is the integration and coordination of the whole life cycle of the project. The complete process is divided into five progressive and interlinked stages of intelligent decision-making, intelligent design, intelligent production, intelligent construction, and intelligent operation and maintenance. Data interoperability and reuse of achievements at each stage eliminate information silos across all links of the traditional model.

In the first stage of intelligent decision-making, the project relies on regional engineering big data, land resource data and carbon emission measurement model to complete project investment estimation, site selection optimization, and low-carbon plan comparison in the early stage, replacing the traditional preliminary planning method of relying on experience estimation. The second stage of intelligent design is based on BIM forward design to complete multi-professional collaborative modeling of architecture, structure, electromechanical, and simultaneously complete pipeline collision verification, prefabricated component splitting and energy consumption simulation. The design results directly transmit digital parameters to the downstream production link. In the third

stage of intelligent production, the factory reads the BIM model split data to complete the automated processing of prefabricated components, and carries the IoT chip to record the whole process information of component production, quality inspection and warehousing. In the fourth stage of intelligent construction, after the prefabricated components are transported to the site, relying on the intelligent site IoT platform to control the lifting and assembly process, the construction robot completes high-precision construction operations, and synchronizes the construction progress, quality and safety data to the digital model in real time. In the fifth stage of intelligent operation and maintenance, a complete digital twin model will be delivered after the completion of the project, and preventive maintenance will be carried out by continuously monitoring of building energy consumption and equipment operation data, until the digital management of material recycling will be completed in the stage of building renovation and demolition [9].

There is no absolute segmented time boundary in the five-stage framework. The digital results output in the pre-stage can be reused in the subsequent link throughout the whole process. The long-term operation data generated in the operation and maintenance stage flows back to the decision-making and design database, providing data support for the optimization of the new project scheme and forming a closed loop of the whole life cycle data [10].

2.3. Comparison of progress at home and abroad

Looking at the development of the global intelligent construction industry, different countries have followed differentiated paths. European and American countries rely on the concept of industry 4.0 to derive the architecture 4.0 system. The core advantages are standardized data interfaces, mature BIM commercial software, and perfect engineering digital laws and regulations. Germany and the United Kingdom forced the full-process application of BIM for large-scale public projects around 2010. The industry has formed a unified ISO19650 data standard, and the threshold for cross-enterprise data sharing of digital platforms is low. At the same time, the industrial Internet is deeply integrated with construction sites, and the penetration rate of automated prefabricated factories exceeds 60%. However, due to the scale of the construction market, the overall industrial landing speed is slow [11]. The focus of Japan's industrial development is focused on the research and development and implementation of construction robots. In the 1980s, leading construction enterprises launched the research and development of construction robots, and developed special automation equipment for dangerous processes such as rebar tying, wall spraying, and high-altitude work, forming a mature model of human-computer collaborative construction. More than 70% of large-scale projects in the country are equipped with construction robots, but the progress of digital collaborative platform construction lags behind, and the popularity of BIM whole-process application is not as high as that in European and American countries [7, 10].

The domestic intelligent construction industry started relatively late. After the Ministry of Housing and Construction issued the first special guidance document for intelligent construction in 2017, the industry entered a high-speed development cycle. Relying on the huge new construction project market to form a large-scale pilot advantage, 24 intelligent construction pilot cities have been established across the country, and the proportion of new construction area of assembly construction has continued to increase. Shanghai, Shenzhen, Chengdu and other cities have achieved full coverage of large-scale public construction projects BIM, rich landing scenarios of digital twins and smart construction site platforms, forming a number of localized practice cases in complex engineering fields such as ultra-high-rise buildings and large-scale transportation hubs [4]. Compared with overseas counterparts, the domestic advantage lies in its huge market size, strong policy support, and diverse digital application scenarios. However, the shortcomings are also

prominent: autonomous controllable high-end engineering software and high-precision sensors are highly dependent on foreign countries, the national unified data interaction standards have not been implemented, the gap in the supply of composite digital talents is significant, and the capital pressure on the transformation of small and medium-sized enterprises is great. The industry as a whole is still in the primary stage of the transition from pilot promotion to large-scale popularization [12].

3. Four major changes in the traditional construction industry driven by intelligent construction

3.1. Design stage

Traditional architectural design has adopted the independent drawing mode by major for a long time. Architectural, structural and mechanical and electrical designers complete the drawing separately. The information of each major is not interoperable, and design errors such as pipeline collisions, dimensional conflicts, and parameter mismatches occur frequently. A large number of design changes in the construction stage of the project not only prolong the construction period, but also bring chain problems such as material waste and floating costs. Multi-professional information barriers are a long-standing pain point that the design link has been unable to eradicate. The BIM collaborative design system reconstructs the professional collaboration mode, and multi-professional designers carry out design work synchronously in the same digital model. The built-in collision detection algorithm of the system automatically identifies professional conflicts, completes the program optimization in advance at the design stage, and reduces the amount of later changes from the source. According to the statistics of BIM application projects in Shanghai in 2025, the error rate of drawing design decreased by 72% in the project using the whole process BIM positive collaborative design, the number of design changes in the construction stage decreased by 65%, and the working hours of multi-professional communication and coordination were compressed by 40%, completely breaking the professional information barriers brought about by traditional segmented drawing [5]. The digital collaboration mode changes the design delivery carrier synchronously. Traditional paper drawings are gradually replaced by digital models that can be updated in real time. Owners, construction and cost units can retrieve model data synchronously. The problem of information transmission distortion is fundamentally alleviated, and the design link has shifted from a single drawing output to full-life cycle digital asset delivery [9].

3.2. Production stage

Traditional construction takes on-site cast-in-place operation as the core production mode. A large number of rebar, formwork and concrete are processed and poured on site. The open-air operation is constrained by the weather, site and manual operation level, and the production efficiency fluctuates greatly. At the same time, on-site cutting and mixing produce a huge amount of construction waste, and the cost of environmental protection management is high. Intelligent construction links with new building industrialization, promotes the transfer of component production to standardized factories, relies on BIM model split data to drive automated production line prefabricated wall panels, floor panels, stairs and other components, only the assembly and splicing process is completed on site, and the production mode has undergone a fundamental change. According to the large-scale pilot data of the industry, compared with the traditional cast-in-place model, the overall construction efficiency of the standardized production of prefabricated factories has been improved

by 30%, the construction waste emissions at the construction site have been reduced by 80%, the component size accuracy error has been controlled at the millimeter level, and the stability of construction quality has been significantly improved [9]. Factory-based production realizes the precise control of the loss of building materials synchronously. Relying on BIM material usage measurement to reduce raw material waste, the consumption of building materials per unit construction area is reduced by 18%, which meets the development requirements of pollution reduction and carbon reduction in the construction field under the double carbon target. The production link has shifted from open-air rough manual operation to workshop automated assembly line production [13].

3.3. Construction stage

Traditional construction site management relies heavily on the on-site inspection of management personnel. Personnel arrival, mechanical dispatching, safety hidden danger investigation, and progress control all rely on manual records. The control coverage is limited, risk disposal is lagging behind, and there is a high incidence of safety accidents such as falling from high altitudes and mechanical injuries. Construction delays and process conflicts have become the norm of the project. Equipped with the intelligent construction site system of the IoT, Artificial Intelligence (AI) video recognition and digital twin, it realizes real-time online control of all elements of construction. The intelligent safety helmet positioning system grasps the workers' activity area in real time. The AI camera automatically identifies dangerous behaviors such as not wearing safety protection and illegal high-altitude work and gives an immediate warning. Tower machines and elevators are equipped with sensing equipment to realize the automatic locking of overload and limit risks. The digital twin model restores the on-site construction progress synchronously, and the management personnel complete the process scheduling and resource allocation online [6]. The summary measurement data of the national intelligent construction pilot project shows that in the comprehensive implementation of the smart construction site control system, the incidence of safety accidents at the construction site has decreased by 60%, the overall construction cycle has been shortened by 20% to 30%, the process conflicts and personnel problems have been greatly reduced, and the construction site management has changed from manual offline rough inspection to digital real-time control of the whole area [14].

3.4. Management stage

Traditional project management decision-making relies on the experience of project managers. Cost measurement, schedule planning and risk prediction lack quantitative data support. Market building materials price fluctuations, process delays, and design changes are very easy to cause project cost overrun and progress out of control. The average cost overrun rate of traditional projects in China has been maintained at more than 18% for a long time, and the accuracy rate of schedule planning is less than 50%. Intelligent construction integrates the big data of the whole process of engineering, builds an integrated project management digital platform, and forms a database of historical similar project costs, construction period and loss data. In the process of new projects, the system compares the budget and actual expenditure in real time, automatically identifies cost deviation nodes, predicts the risk of construction delay based on machine learning algorithms, and provides quantitative decision-making basis for management [8]. According to the background statistics of digital projects of domestic leading construction enterprises, the overall cost overspending of engineering projects that adopt data-driven management mode has decreased by 15%, the accuracy of the implementation

of the schedule has increased to 90%, the efficiency of capital, materials and manpower scheduling has been significantly optimized, and the underlying logic of project management has changed from subjective experience judgment to objective data quantitative analysis [12].

4. The development challenges of China's intelligent construction

4.1. Technical dependence dilemma

The foreign dependence of domestic intelligent construction core software and hardware is high. Industry research data shows that imported products of high-end BIM modeling software, high-precision site sensing equipment and automated engineering machinery controllers account for more than 70% of the market. Local independent research and development products can only cover basic lightweight application scenarios, and core graphics engines, sensing chips and control algorithms have been monopolized by overseas enterprises for a long time [2]. External dependence on technology brings two layers of reality constraints. One is the long-term high cost of use. Overseas commercial BIM software charges high licensing fees by project and year. The procurement and maintenance of high-precision sensors are expensive, which continues to increase the digital transformation expenditure of enterprises. Second, there are hidden security risks of engineering data. The complete building model, cost data and construction site monitoring data of the project are stored on the servers of overseas software service providers. There is a risk of leakage of large-scale public buildings and municipal infrastructure engineering data, which is not conducive to the security control of urban digital infrastructure. Although domestic scientific research institutions continue to carry out independent engineering software research and development, the underlying graphics engine and simulation algorithm have a long cycle, and it is difficult to completely replace imported products in the short term. The core technology bottleneck has become the underlying bottleneck that restricts the large-scale promotion of the industry [12].

4.2. Standard-missing dilemma

The basis of the whole process of intelligent construction coordination is a unified data interaction standard. At present, only some sub-field recommended specifications have been introduced in China. The national unified data interface standard covering the whole chain of design, production, construction, operation and maintenance is still in the preparation stage. The data formats of BIM platforms and smart construction site systems developed by different enterprises and different regions are incompatible, and model files cannot be interoperable across platforms. Each project and enterprise forms an independent data island. It is difficult to achieve data sharing in the whole industrial chain, and the reuse value of digital assets is greatly reduced [4]. The lack of unified data standards further raises the cost of multi-platform docking and transformation of enterprises. Small and medium-sized enterprises are unable to complete multi-system data adaptation, and the willingness to participate in digital transformation continues to decline [15].

4.3. Talent fault dilemma

Intelligent construction puts forward interdisciplinary ability requirements for practitioners. Practitioners need to master digital skills such as civil engineering expertise, BIM modeling, IoT operation and maintenance, and big data analysis at the same time. At present, there is a huge gap in the supply of composite talents in the domestic industry. The shortage of composite intelligent

construction talents in the industry has reached hundreds of thousands, and the problem of talent faults continues to restrict the implementation and promotion of the industry. At the level of existing practitioners, traditional civil engineering construction and design personnel have been practicing for a long time, and the coverage of digital skills training is insufficient. According to industry sampling research, the proportion of traditional civil engineering practitioners with complete BIM and digital platform operation capabilities is less than 10%. Most front-line technicians only master the basic drawing reading and cannot adapt to the digital collaborative working mode [15]. There is a lag in the talent training system of colleges and universities. Traditional civil engineering undergraduate courses are mainly based on traditional contents such as structural mechanics and construction technology. The proportion of courses related to computer, digital twins and engineering big data is extremely low. The scale of cross-degree training in civil engineering and computer is limited, and the number of composite professional talents exported every year is far lower than market demand. The phenomenon of talent loss in the central and western regions further exacerbates the imbalance between regional talent supply and demand.

4.4. Cost threshold dilemma

There is a significant threshold for fixed asset investment in the early stage of intelligent construction. Complete digital transformation includes BIM software procurement, smart site sensing equipment deployment, digital management platform construction, automated prefabricated production line acquisition and other expenses. The early investment of a full set of intelligent construction systems for large and medium-sized new projects is relatively high. The smaller the project volume, the higher the digital sharing cost of the unit construction area, and the profit space is greatly compressed. The impact of capital pressure on small and medium-sized construction enterprises is the most obvious. The main market subjects of the domestic construction industry are mainly small and medium-sized construction and design enterprises. The cash flow of enterprises is tight and the financing channels are narrow, and they cannot afford to undertake the high amount of early digital investment. Digital applications are only limited to simple BIM modeling and other basic scenarios, and the whole process of intelligent construction and landing cannot be realized. The return cycle of short-term digital investment is relatively long. Most projects need 2 to 3 complete engineering cycles to recover the early transformation cost. The market lacks supporting financial subsidies and industrial financial support policies, which further reduces the enthusiasm of small and medium-sized enterprises for digital transformation, and the process of industrial scale popularization is hindered [1].

5. Suggestions for the development of intelligent construction in China

5.1. Short-term strategy

The short-term core goal of industrial development is to lower the threshold for the transformation of market entities and rapidly expand the coverage of technology basic applications. At the financial level, local housing and construction departments, together with financial institutions, have issued special subsidies for the procurement of local independent BIM software and domestic sensing equipment, and subsidies of 3%-5% of the project cost for the selection of domestic software and hardware. Simultaneously reduce the authorization and use of domestic engineering software taxes, hedge the cost advantages of overseas products, and relieve the pressure of core technology procurement funds of enterprises. Launch a free trial policy for lightweight digital platforms for

small and medium-sized enterprises to reduce the initial digital investment cost [12]. At the level of talent cultivation, relying on provincial construction vocational colleges and universities and local head construction enterprises to jointly build regional intelligent construction training bases, and configure BIM workstations, construction robots, and intelligent construction site simulation system practical equipment. Carry out short-term digital skills rotation training for traditional civil engineers, open BIM collaboration and IoT site control practical courses, and complete the upgrading of the digital ability of stock practitioners. Simultaneously implement the digital skill post allowance system to encourage front-line technical personnel to actively participate in training and quickly fill the gap of basic composite operation talents [15]. In terms of data security, the local storage of engineering data is mandatory in the short term, requiring all municipal and public construction projects to adopt local digital platforms to avoid the risk of overseas software data leakage.

5.2. Medium-term strategy

The medium-term development of the industry focuses on the improvement of the institutional system and the supply of industrial funds, and breaks down the two core obstacles of data islands and financing constraints. At the level of standard construction, China should accelerate the compilation and implementation of national intelligent construction full-life cycle data interaction standards, complete the national standards for unified BIM models, IoT monitoring data and prefabricated components digital delivery interfaces, unify the national digital platform data format, open up cross-link and cross-enterprise data flow channels for design, production, construction, operation and maintenance, integrate the unified data interface into the national intelligent construction project star rating evaluation hard indicators, and force enterprises to complete the adaptation and transformation of digital platforms [4]. In terms of financial support, the Ministry of Housing and Construction and local governments should set up a special guidance fund for the intelligent construction industry to provide low-interest loans and equipment financing and leasing services for small and medium-sized construction enterprises that carry out digital transformation, and provide special credit support for the construction of automated production lines in prefabricated factories. Encourage banks to develop special insurance products for intelligent construction projects to hedge the investment risks of digital transformation of enterprises [12]. At the industrial ecological level, promote the industrial chain coordination of software enterprises, equipment manufacturing enterprises and construction enterprises, build a joint innovation platform for domestic software and hardware, accelerate the iterative upgrading of local core technologies, and gradually narrow the performance gap with overseas products [4].

5.3. Long-term strategy

The long-term development goal is to realize the autonomy and controllable core technology, the long-term effectiveness of the talent supply system, and build a sustainable intelligent construction industrial ecology. In terms of the restructuring of the talent training system, the Ministry of Education promotes the reform of the national civil engineering undergraduate professional curriculum, adds core courses such as digital twins, engineering big data, construction robots, etc., expands the enrollment scale of cross-double degrees in civil engineering and computer science, promotes the joint construction of industry-academia-research joint laboratories between universities and construction central enterprises and digital technology enterprises, integrates the digital practice of the project into the compulsory practice link, and stabilizes the long-term supply of composite

talents from the source. Simultaneously improve the training system of digital craftsmen in vocational education, open up the upward channel of digital talents in technical secondary school, higher vocational and undergraduate, and cover the needs of talents at all levels of management, technology and operation [15]. At the level of core technology, relying on the national key research and development plan to set up a special project for intelligent construction of underlying software, focus on BIM underlying graphics engine, high-precision sensing chips, automated control algorithms and other core technologies, establish an independent intellectual property engineering software system, and realize the comprehensive localization and replacement of high-end software and hardware [2]. Improve the relevant laws and regulations of intelligent construction in the long term, clarify the property rights of engineering digital assets, data circulation standards, and the division of quality responsibilities of digital projects, form a complete institutional guarantee system, and promote the shift of intelligent construction from policy pilot to the mainstream construction mode of industry normalization.

6. Conclusion and outlook

6.1. Conclusion

Relying on the five-stage theoretical framework of the whole life cycle of intelligent construction, this article sorts out the four core technical coordination logics of BIM, the IoT, intelligent engineering machinery and engineering big data, compares the differentiated development paths of domestic and foreign industries, quantitatively analyzes the systematic changes of intelligent construction to the four links of traditional construction industry design, prefabricated production, on-site construction and project management, identifies the four core bottlenecks in the current domestic industrial transformation, and puts forward layered development countermeasures from the three dimensions of short-term, medium-term and long-term.

First, intelligent construction can systematically solve the inherent contradictions of high consumption, low efficiency, high risk and rough control in the traditional construction industry through the whole chain of digital technology. It has clear quantitative benefits in reducing design errors, shortening the construction cycle, reducing construction waste, controlling project costs, and improving construction safety. It is the core path for the industry to crack the efficiency paradox and implement the dual-carbon goal. Its transformation effect is realized by the five-stage data coordination mechanism of the whole life cycle, and the fragmented application of a single technology cannot fully release the dividend of industrial transformation. Second, global intelligent construction has formed a differentiated development path. Europe and the United States rely on unified data standards to cultivate BIM in the whole process. Japan focuses on building robot automation operations. China relies on the huge market scale to realize the rapid landing of the scene. However, the four bottlenecks of core software and hardware are external dependence, lack of unified data standards, insufficient supply of composite talents, and high early transformation costs. Jointly restrict the popularization of industrial scale. Small and medium-sized enterprises are constrained by capital and technology, and the progress of digital transformation lags significantly behind that of large-scale central enterprises. Third, the upgrading of intelligent construction industry cannot be completed in the short term by relying on a single policy and a single subject. It needs to be implemented according to the industrial development cycle. In the short term, relying on financial subsidies and practical training bases to quickly lower the threshold of transformation and expand the scale of basic application. In the medium term, the national unified data standard will be implemented and industrial funds will be established to break the data islands and financing

constraints. Only by restructuring the talent training system of colleges and universities for a long time, tackling the core technology at the bottom, and realizing the independent and sustainable development of the industry, policies, industry, education and scientific research can promote the complete transformation of the industry.

6.2. Outlook

Although this article systematically outlines the technical system and full-life cycle coordination framework of intelligent construction, it has certain limitations. The analysis is based on industry public statistics, local standard documents, and secondary literature, without field questionnaire surveys of front-line construction enterprises. There is a lack of first-hand micro-operation data support at the enterprise level. The differentiated comparative analysis of the transformation resistance and transformation benefits of construction enterprises of different scales and market entities in different regions is insufficient. Follow-up studies may select large, medium-sized and small construction enterprises to carry out field research, quantitatively measure the differences in input and output of digital transformation of different enterprises, and improve the understanding of differentiated transformation paths. At the same time, this article focuses on industrial macro development countermeasures, and does not deeply explore the subdivision system issues such as legal norms of intelligent construction data security, digital asset pricing, and cross-enterprise data sharing revenue distribution. In the future, further investigation can be carried out in combination with the cross-perspectives of jurisprudence and industrial economics.

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