Research Article

Research on the Relationship between Construction 4.0 and Construction Firm’s Performance: Based on the Mediating Role of Technological Innovation Capability

Xiaozhuang Yang,1 Dejian Wu,1,2 and Zhizhe Zheng3

1School of Energy and Civil Engineering, Harbin University of Commerce, Harbin 150028, China
2School of Management, Harbin University of Commerce, Harbin 150028, China
3School of Civil Engineering, Northeast Forestry University, Harbin 150040, China

Correspondence should be addressed to Xiaozhuang Yang; 101039@hrbcu.edu.cn

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1. Introduction

The construction industry is a pillar industry in China and plays an important strategic role in supporting the national economy [1]. During the “13th Five-Year Plan” period, the total output value of China’s construction industry has grown steadily at a rate of 10%, reaching 29.3 trillion yuan by 2021. Although the construction industry has a high total output value and added value [2], the industry still faces many challenges, including low productivity, poor industry image, low predictability, lack of investment in R&D and innovation, structural fragmentation, and poor technological progress [3, 4]. Since its inception, the construction industry has sought ways to reduce costs, increase efficiency, enhance visualization, strive to shorten delivery times, improve data sharing, reduce construction waste, increase productivity and sustainable performance, improve safety, and improve quality [5]. New technologies brought about by Industry 4.0 offer this possibility [6]. Therefore, it is necessary to carry out technological innovation to effectively manage construction projects, improve productivity, and promote construction industrialization and industrial modernization [1].

The fourth industrial revolution, characterized by the convergence of emerging technologies, is rapidly changing the industrial environment [7]. Industry 4.0 aims to combine multiple technologies for mutual benefits, enabling responsiveness and improving the quality of production systems [8]. The concept is broad and considers many aspects of interdisciplinary technology and collaboration, which are essential for continuous automation through disparate processes [9]. Various digital technologies have
also improved the quality and productivity of the manufacturing industry, causing the manufacturing industry to undergo fundamental process changes [10]. Industry 4.0 has become an important way for firms to gain the advantage of sustainable development [8]. With the advent of Industry 4.0, the forces of globalization and digitalization are driving the construction industry to advance the process of digitalization to improve the efficiency of the industry [11]. Advances in new technologies in recent decades have led to a new concept proposed in Germany in 2016, Construction 4.0 [12]. Construction 4.0, by integrating emerging technologies such as Building Information Modeling (BIM), Augmented Reality (AR), Virtual Reality (VR), Internet of Things (IoT), blockchain technology, etc. [7], penetrates into all stages of the building life cycle and plays an important role [13]. These emerging technologies can bring economic benefits, increase efficiency, productivity, quality, and collaboration, help improve sustainability and safety, and restore the bad image of the construction industry [14]. For example, BIM can increase cooperation between different project stakeholder groups, providing tools for transformation and improvement of project performance and productivity [15]. Artificial Intelligence offers great potential for greatly improving efficiency by quickly and accurately analyzing large data volumes [5]. The implementation of IoT can improve transparency and traceability [16], thereby reducing costs, reducing waste [8], and improving construction safety and productivity [17]. The use of smart construction sites can save costs and time and improve the productivity and safety of construction projects [6]. Energy-saving technologies help to build a more sustainable industrial structure to promote technological innovation [18]. Through the effective use of blockchain technology, transaction costs can be significantly reduced while greatly improving security [7]. 3D printing and autonomous robots promise to reduce the risks that workers encounter in construction projects [19], reduce labor and material costs, increase productivity, and even create more jobs [20]. AR and VR help to improve communication and collaboration, improve project understanding, increase productivity, reduce project expenses, and facilitate the adoption of other emerging digital technologies [21]. While improving safety, big data are expected to improve productivity and shorten construction duration and cost [22].

Construction 4.0 has continued to grow rapidly over the past few years and represents one of the fundamental themes of our current digital age. Existing research on the relationship between digital technology and firm performance is still controversial, and some scholars believe that digital technology actively promotes firm development. For example, digital transformation can significantly improve the information processing capability of firms, promote the flow and sharing of information and knowledge elements within the firm [23], alleviate the problem of information asymmetry [24], and reduce the search, development, production, operation, maintenance, management, and governance costs [25–27], improve the technological innovation capability of firms [28], promote the optimization and upgrading of organizational structure and production and operation process optimization [29], and promote business model innovation [30]. On the other hand, the view that the application of digital technology can directly promote firm performance has been questioned by some researchers [31]. Li and Jia [32] believe that the use of information technology alone cannot affect the change of firm performance, but the support of information technology can only be played through the arrangement of resources. Jiang et al. [33] analyzed the impact of digital transformation on firm innovation and believed that the process of digital transformation will generate a large learning cost, which may be the reason that hinders the positive effect of digital advantages. Qi and Cai [34] also believe that a large number of derived management costs are generated in the process of firm digital transformation, which will seriously weaken its effect on firm performance. Hajli et al. [35] analyzed the influence of firm heterogeneity on this promotion and found that the level of digitalization can only improve the operation level of those firms that are more dependent on digital technology, such as information and communication industry and software and Internet firms. However, the impact on traditional manufacturing and real estate has not shown a promotion effect. Usai et al. [36] argued that digital capabilities have little or no impact on firm performance and point out that firms’ innovation performance is not the result of digital capabilities, but the result of creativity and continuous efforts in R&D activities. This suggests that digital capabilities alone are not sufficient to achieve successful innovation performance [37]. Digital technology may have an indirect impact on firm innovation performance through other influences on other variables [36]. Although digital technology can promote firm performance, if firms want to make full use of digital technology in the innovation process, they need to have sufficient technological innovation capabilities to integrate and mobilize human and technological advantages to speed up the innovation process [38].

Through literature review, it was found that, research on Construction 4.0 is mainly conducted at the conceptual level, focusing on new applications of existing technologies [9], and few scholars empirically study the impact of the implementation of Construction 4.0 on firm performance. Although experience in other industries suggests that these benefits are achievable, there is no conclusive evidence of these benefits in construction [21]. It is therefore necessary to identify potential benefits to incentivize the construction industry to apply new technologies [39] and to enhance the technology’s reputation [21]. From the perspective of technological innovation capability, this paper analyzes the direct impact of Construction 4.0 on firm performance, and on this basis, with technological innovation capability as an intermediary, it continues to explore the internal mechanism of the connection between Construction 4.0 and firm performance. The possible main contributions of this paper are as follows: First, referring to the text mining method in economic research, using the frequency of relevant keywords to construct relevant indicators, it solves the difficult problem of quantitative measurement of Construction 4.0, and by exploring the mediating role of technological
innovation capability, it makes up for the existing insufficient research on the internal mechanism of the link between Construction 4.0 and firm performance in the study. Second, from the macroscopic to the microscopic research perspective, the empirical model is used to verify the impact of Construction 4.0 on firm performance, which enriches the research on the implementation effect of Construction 4.0. The conclusions of this study provide empirical evidence and policy support for the continuous deepening of digital transformation of Chinese firms, which can promote the digital transformation of construction firms, strengthen technological innovation, and create new development momentum.

2. Theoretical Background and Assumptions

2.1. Implication of Construction 4.0 on Firm Performance. The “Digital Architecture! White Paper 2021” pointed out that the so-called Construction 4.0 is based on the concept of Digital Twins and comprehensively uses cutting-edge technologies such as 5G, BIM, Internet of Things, and blockchain to realize all participants and all elements, and the whole process is intelligent and digitized, so as to build a new platform ecological system for industries, firms, and projects. Construction 4.0 represents the exploration of new technologies in the construction industry, equivalent to Industry 4.0 in manufacturing [9]. In recent years, Construction 4.0 has had a huge impact on global construction activities [40], and the global construction industry has begun to adopt digital technologies to improve operations and productivity [19]. Technological advances brought about by Construction 4.0 can provide solutions to many problems in current architecture and have played an important role in architecture [41]. In almost every area of project management, Construction 4.0 can bring enormous benefits, including time savings, cost savings, improved quality and collaboration, and enhanced safety and sustainability [42]. Construction 4.0 is not only a traditional building upgraded through technological innovation, but also a new way of perceiving and understanding architecture through innovation and increased productivity [14].

2021 is the first year of the “14th Five-Year Plan.” With the vigorous promotion of new infrastructure construction and urban new infrastructure construction, digital technology represented by BIM is effectively transforming the development model of the construction industry and promoting the development of intelligent buildings, to help the entire industry accelerate digital transformation. Digital transformation refers to the process in which firms use various digital technologies in business models and strategic thinking to achieve firm reform in order to improve their performance and competitiveness during innovation [33, 43, 44]. This has changed the organizational model, strategic flexibility, and business development model of the firm, which has a positive impact on the operational performance of the firm [45]. Chen et al. [46] believe that the unique rhythm and trajectory of digital technology will enable firms to carry out innovative transformation behaviors, thereby improving economic performance. Fan and Liu [47] concluded through empirical research that digital transformation of firms can significantly improve the firm’s operating performance. Liu [48] also found that the digital transformation of firms can improve the production efficiency of firms and promote the realization of high-quality development of firms. Ren and Meng [45] pointed out that the diversified value creation method endowed by digital transformation has an efficient way of realizing it, which has opened up more channels for firms to improve performance and benefits. The resource-based theory assumes that resource differences between organizations are the root cause of firm performance gaps. Resource constraints have always been an important problem that competitive firms try to solve. The digital embedding helps firms to break down the barriers of physical resources and effectively alleviate the problem of resource constraints [49]. Digital transformation provides an effective transformation and upgrading idea for firms to improve their own resources and capabilities and to amplify their potential with the help of external entities and promote the realization of high-quality development of firms [45]. Consequently, we propose the following hypothesis.

Hypothesis 1. Construction 4.0 is positively correlated with firm performance.

2.2. Implication of Construction 4.0 on Technological Innovation Capability. Technological innovation capability refers to a firm’s ability to develop new products and services by integrating its strategy with innovation processes [50]. These capabilities include the knowledge and skills to acquire, use, absorb, adapt, improve, and generate new technologies [51], contribute to the development of new products and technologies, improve manufacturing processes and quality control skills, and predict technological changes in the industry [52]. Technological innovation capability has long been regarded as the backbone of economic growth and the main source of a firm’s competitive advantage [53]. Technological innovation has a large enough potential to achieve firm change [54].

All along, various digital technologies have promoted firm innovation [55]. The application of digital technology promotes the improvement of the firm automation level, business process improvement, and cost saving [56], helps firms to realize the complementary innovation network, promotes the exchange and sharing of digital knowledge and technology [57], and stimulates the spirit of firm innovation [58], which strengthens the firm’s ability to integrate internal and external information and its sensitivity to forward-looking technologies and minimize innovation risks [59]. Liu et al. [60] pointed out that firm digitization can reduce the coupling loss of resources in the process of technological innovation, alleviate resource misallocation, improve internal synergy, reduce innovation costs, and provide necessary conditions for the improvement of technological innovation capabilities of firms and found that the level of firm digitization has improved 1% which can promote technological innovation capability by 18.29%. Xu [61]
pointed out that, in the process of digital empowerment, firms will reconstruct their original organizational capabilities, accelerate the application and integration of digital technologies in innovation activities, and form organizational dual capabilities for exploration and utilization in the field of R&D innovation, thereby enhancing the technological innovation capabilities of firms.

During the “14th Five-Year Plan” period, the dependence of social and economic development on scientific and technological innovation has gradually deepened. In the digital economy era, digital technology means and abundant big data resources will play a supporting role while firms optimize their technological innovation models [62]. The development of various digital technologies promotes the development of innovation and improves the efficiency of firms. In order to improve value production and business model innovation, digital technologies are applied in all aspects of business management, which innovate willing power [55]. Consequently, we propose the following hypothesis.

**Hypothesis 2.** Construction 4.0 is positively correlated with technological innovation capability.

### 2.3. Implication of Technological Innovation Capability on Firm Performance

**Under the current international market situation and domestic economic conditions, in order to promote long-term development, firms often turn their development models into innovation-driven ones.** In this process, people pay more and more attention to the ability of technological innovation. The research on the impact of technological innovation capability on firm performance has long been concerned with the industry and academia, and the research content is also deepening. However, the previous research was more on all listed firms or technology-intensive industries and fast-growing manufacturing industries. The research on the construction industry is rare. Through theoretical analysis and empirical research, most scholars have come to the conclusion that technological innovation capability can positively promote the growth of firm performance and financial performance [63–66]. Murphy and Schlegelmilch [67] showed through research that the higher the investment in technological innovation in the US manufacturing industry, the better the firm performance. Liu and Yang [68] used the data of 2956 firms as a research sample and concluded that the R&D investment and the number of patents of listed firms have a positive effect on improving corporate performance. Shan et al. [69] took China’s small- and medium-sized board listed firms as the research object, studied the impact of technological innovation on firm performance, and found that technological innovation had a significant positive effect on firm performance. Schumpeter’s innovation theory believes that only technology and knowledge innovation can promote firms to obtain competitive advantages, and new technologies and new products can also be used as heterogeneous resources to improve firms’ market competitiveness and ultimately improve performance [70]. Li and Chen [71] pointed out that the dynamic ability of technological innovation can effectively reduce production costs, improve production efficiency, improve product performance and environmental adaptability, etc., and make it possible to improve the core competitiveness, market share, and operating efficiency of firms, thereby promoting the improvement of firm performance. Firms with high technological innovation capabilities can achieve impressive results. Organizations with high levels of innovation tend to improve organizational performance faster than those with no innovation activities [72]. In contrast, the construction industry has received less attention in this area. According to research by Lee et al. [73], investment in technological innovation is a long-term process, and technological innovation improves firm performance by increasing contractor productivity and quality levels. Consequently, we propose the following hypothesis.

**Hypothesis 3.** There is a positive correlation between technological innovation capability and firm performance.

**To sum up, Construction 4.0 can improve the technological innovation capability of firms, which in turn improves firm performance.** Technological innovation capability plays a positive mediating role in firm performance promotion during Construction 4.0. Consequently, we propose the following hypothesis.

**Hypothesis 4.** In the process of Construction 4.0 to promote firm performance, technological innovation capability plays a positive mediating role.

### 3. Research Design

#### 3.1. Sample and Data Collection

This paper takes 33 listed construction firms in China as the research object. Because the first article mentioning Construction 4.0 was published by Li and Shi [74] in 2015, the research time frame of this paper is 2015–2020. The relevant data to measure Construction 4.0 comes from the annual reports of listed firms. Relevant financial indicators come from the CSMAR database, and the annual reports of listed firms are obtained from http://www.cninfo.com.cn. In order to ensure the accuracy of the empirical test, some samples with partial missing data were eliminated, and 168 observation samples were obtained in the end. Data processing and analysis are mainly with the help of SPSS 23 and STATA 15.

#### 3.2. Variable Definition

**3.2.1. Dependent Variable.** This paper chooses return on equity (ROE) to reflect the level of firm performance. It is a highly representative and comprehensive financial indicator to represent the financial efficiency and solvency of a firm.

**3.2.2. Independent Variable.** At present, the measurement of firm Construction 4.0 level has yet to be developed. This study collects information related to Construction 4.0 in the annual reports of listed firms. If the target keyword appears more frequently, it indicates that the target firm is more
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Table 1: Selection of technical innovation capability indicators.

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<tr>
<th>Indicators</th>
<th>Indicator composition</th>
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<tr>
<td>R&amp;D personnel technical ratio</td>
<td>Total number of technicians/total number of employees</td>
</tr>
<tr>
<td>The proportion of employees with a bachelor's degree or above</td>
<td>Number of patents in the current year</td>
</tr>
<tr>
<td>Number of patents in the current year</td>
<td>Total number of employees with bachelor degree or above/total number of employees</td>
</tr>
<tr>
<td>R&amp;D investment intensity</td>
<td>Number of patents in the current year</td>
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<td></td>
<td>R&amp;D investment/main business income</td>
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Finally, according to the variance contribution of the two principal components, the comprehensive score of technological innovation capability is calculated as follows:

\[ F = 0.639F_1 + 0.361F_2. \]  

3.3. Model Settings. In order to analyze the influence between Construction 4.0, technological innovation capability, and firm performance, this paper draws on the study of the mediation model by Wen et al. [76] and establishes the following model to test this hypothesis:

\[ \text{ROE} = \alpha_1C_4 + \alpha_2\text{Age} + \alpha_3\text{Lev} + \alpha_4\text{Cme} + \alpha_5\text{Ttc} + \epsilon, \]  

\[ \text{Inf} = \beta_1C_4 + \beta_2\text{Age} + \beta_3\text{Lev} + \beta_4\text{Cme} + \beta_5\text{Ttc} + \epsilon, \]  

\[ \text{ROE} = Y_1C_4 + Y_2\text{Inf} + Y_3\text{Age} + Y_4\text{Lev} + Y_5\text{Cme} + Y_6\text{Ttc} + \epsilon. \]

4. Results

4.1. Descriptive Statistics. As shown in Table 3, the maximum value of firm performance is 26.40, the minimum value is −4.260, and the average value is 8.649. The average performance level of construction firms is relatively high, and the differences between different construction firms are obvious. The maximum value of the technological innovation capability is as high as 3.759, the minimum value is only −1.004, and the average value is 0. It shows that there is a big difference in the level of technological innovation capability of construction firms. The maximum value of Construction 4.0 is 0.194, the minimum value is 0, the mean value is 0.031, and the value of some firms is 0, indicating that digital construction technology is hardly used. Large max-min gap and variance of control variables such as Lev and Cme have a significant impact on dependent variables.

4.2. Correlation Analysis. Table 4 shows the results of the Person correlation test in the model. Both Construction 4.0 and technological innovation capability have a significant positive correlation with firm performance, meaning hypothesis H1 and hypothesis H3 are verified. There is also a significant positive correlation between Construction 4.0 and...
and technological innovation capability, where hypothesis H2 is verified. Among the control variables, Cme and Age have no significant correlation with other variables, indicating that Age and Cme of construction firms are not the key factors affecting performance and innovation, while Lev and Ttc have significant correlation with most other variables, which are more suitable as a control variable.

4.3. Regression Analysis. Regression analysis was used to verify the relationship between the hypothesis of Construction 4.0, technological innovation capability, and firm performance. The results are shown in Table 5. Model 1 is the relationship between Construction 4.0 and firm performance. The regression results show that Construction 4.0 is significantly positively related to firm performance, which verifies hypothesis H1. From the results of Model 2, it can be seen that the impact of Construction 4.0 on technological innovation capability is significantly positive at the 1% level. This shows that Construction 4.0 has a significant role in promoting technological innovation which verifies hypothesis H2. Model 3 is the relationship between Construction 4.0, technological innovation capability, and firm performance. It can be seen that technological innovation capability is significantly positively correlated with firm performance, which verifies hypothesis H3. Combining Models 1, 2, and 3, the conclusion is that technological innovation capability has an intermediary role while applying Construction 4.0 to promote firm performance. Hypothesis H4 is verified.

4.4. Robustness Test. In order to test the robustness, the return on total assets in this paper is a surrogate variable. As the regression results in Table 6, besides the coefficient change, there is still a significant positive correlation between the main indicators, which is not much different from the previous results. It can be concluded that the research model and conclusions selected in this paper have certain robustness.

5. Discussions

The conclusions of this paper are as follows: First, there is a significant positive correlation between the level of Construction 4.0 and firm performance. This result shows that firms that apply Construction 4.0 technologies tend to achieve higher firm performance. Results are similar to the studies of García de Soto et al. [77] and Ghaffar et al. [78]; Construction...
By exploring the mediating role of technological innovation capability, it is inseparable from the technological innovation capability to integrate and mobilize human and technological advantages.

6. Conclusions

The “14th Five-Year Plan” proposes that China should promote the digital transformation of its industries, so the current construction industry needs an urgent transformation, to focus on quality and efficiency instead of scale and speed. For some time to come, digital technology will be a new driving force of construction industry development, which pushes the transformation of construction models and the development of engineering technology. This Construction 4.0 model will change the construction industry, improve the productivity of construction firms, and promote the construction industry to adapt to innovation. The innovation capability based on the digital construction model will be the core competitiveness of the construction industry. Based on a microscopic perspective, this study takes 2015–2020 listed firms in China’s construction industry as a research sample and uses the mediation effect test to empirically discuss the impact of Construction 4.0 on firm performance and its mechanism. The research results show that Construction 4.0 can help improve firm performance. Secondly, the implementation of Construction 4.0 has a significant promoting effect on strengthening technological innovation capability, and technological innovation capability plays a positive intermediary role in the process of Construction 4.0 improving firm performance. The conclusions of this paper have certain practical implications for construction firms to promote Construction 4.0 and encourage construction firms to achieve high-quality development [3, 4, 25, 27, 43, 44, 63, 66, 79].

7. Theoretical and Practical Implications

7.1. Theoretical Implications. Construction 4.0 is an inevitable direction for the future development of firms, and the importance of research on the mechanism of construction firms cannot be ignored. The theoretical implications of this paper are as follows: First, the current research on the impact of Construction 4.0 on the performance of construction firms is only at the level of results, lacking the exploration of the internal mechanism. Referring to the text mining method in economic research, this paper uses the frequency of keywords to construct relevant indicators and solves the problem of quantitative measurement of Construction 4.0. By exploring the mediating role of technological innovation capability
capability, it makes up for the lack of research on the internal mechanism of the connection between Construction 4.0 and firm performance in existing research.

Second, research on Construction 4.0 is mainly conducted at the conceptual level, focusing on new applications of existing technologies, lacking empirical evidence to bridge the theoretical gap between existing literature and practical issues. Therefore, this paper changes the research perspective from macro to micro and uses an empirical model to verify the impact of Construction 4.0 on firm performance, which enriches the research on the implementation effect of Construction 4.0.

8.1. Limitations. Although the hypothesis proposed in this study has been verified, there are still some limitations due to the research conditions. First, the framework is based on Chinese conditions, only Chinese construction firms are studied, and the sample size is small. Due to the different structure, dynamics, market, stakeholders, firms, customers, labor force, etc. of the construction industry in different regions, the results given in this study may not be fully generalizable to other regions, which may be different from other developed countries. Future research could use data from other emerging markets to test the generalizability of our results.

Second, this study uses patents and R&D expenses as part of the measurement of technological innovation capabilities. Some small- and medium-sized firms do not have invention patents and R&D expenses or do not disclose relevant information, which may bias the results.

Third, the impact of Construction 4.0 on firm performance may have multiple paths, and this study only confirms that technological innovation capability plays a partial mediating role in the relationship between Construction 4.0 and firm performance.

8.2. Future Research Directions. In the past, the research on digital transformation has mostly started from the perspective of technology, thinking that digital transformation is the application of digital technology in the production and operation of firms, and the definition of digital transformation is also defined around digital technology [83]. In recent years, with the advancement of digital technology and the continuous deepening of the degree of integration with the real economy, the research on digital transformation not only is limited to digital technology but also has begun to look at the digital transformation from the perspective of organizational change [84]. The concepts of Industry 4.0 and Construction 4.0 involve not only new technologies but also organizational innovation, management, and process aspects [85]. Although the research on Construction 4.0 mainly focuses on technology, technology alone cannot solve all challenges, management also plays a key role [86], and firms should consider both social and technological factors [87]. Industry 4.0 brings new business models [88], so future research can incorporate management innovation capabilities, business models, organizational innovation, management structure, corporate culture, etc. into the influencing factors to help firms carry out digital transformation.

Second, the construction industry in most developing countries of the world is flooded with small- and medium-sized firms [89]. Small- and medium-sized firms lack the financial and technical capabilities for digital transformation [20], invest relatively little in emerging technologies [17], and have almost no R&D investment and patents, making it difficult to measure their technological innovation capabilities. Therefore, future research can develop a new measurement system to evaluate the technological innovation capability of small- and medium-sized firms to expand the research scope and draw more reliable conclusions.

Third, our findings demonstrate that the use of Construction 4.0 technologies positively promotes firm performance. The previous literature is mostly about the specific application of new technologies in the construction industry, and few scholars consider the potential synergistic effects of
these technologies [9]. Compared with the separate application of new technologies, the integration of multiple technologies will bring more potential benefits and opportunities [14]. Therefore, it is imperative to explore the synergies of Construction 4.0 technologies in construction projects to optimize and address future environmental challenges [9]. In addition, other emerging technologies may also have a beneficial impact on the construction industry. Quantum computing is a quantum-mechanical-based technology capable of rapidly solving complex computations while processing and transmitting information [90]. A growing number of other industries and sectors have recently recognized its potential for practical application [91]. For example, quantum computing applications in sectors such as healthcare, finance, and energy have the potential to increase the efficiency and effectiveness of business processes [92]. The mixed use of quantum computing and blockchain technology has the potential to improve information privacy and security [93], and it has important advantages in technological transformation in the corporate world [94]. Therefore, scholars can study the specific application of other emerging technologies such as quantum computing in the construction industry to promote the digital transformation of construction firms.

Data Availability

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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