Hindawi
Mathematical Problems in Engineering
Volume 2022, Article ID 8523480, 12 pages
https://doi.org/10.1155/2022/8523480

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 Zheng**[3]

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

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

Received 13 April 2022; Revised 11 July 2022; Accepted 27 July 2022; Published 25 August 2022

Academic Editor: Antonio Forcina

With the growth and development of Construction 4.0, new technologies such as BIM, Big Data, and the Internet of Things are commonly used. These digital technologies play a critical role in fostering firm innovation and also have a major impact on firm performance. Based on panel data of 33 listed construction firms in China's construction industry from 2015 to 2020, this paper uses regression analysis and mediation analysis methods to empirically examine the relationship between Construction 4.0, technological innovation capabilities, and firm performance. The results demonstrate that Construction 4.0 has a significant positive promotional effect on the firm performance, while technological innovation capabilities mediate between Construction 4.0 and the firm performance. Based on these findings, it is suggested that construction firms should pay attention to the new technologies brought by Construction 4.0, increase investment in research and development, actively cultivate technological innovation capabilities, and build technological innovation networks, so as to promote digital transformation of construction firms.

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 of 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 eta l. [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

Table 1: Selection of technical innovation capability indicators.

Indicators	Indicator composition
R&D personnel technical ratio	Total number of technicians/total number of employees
The proportion of employees with a bachelor's degree or above	Total number of employees with bachelor degree or above/total number of employees
Number of patents in the current year	Number of patents in the current year
R&D investment intensity	R&D investment/main business income

concerned about the key technology represented by the vocabulary [75]. Based on a review of existing research on Construction 4.0 by sorting out and summarizing the relevant literature of Construction 4.0, the keywords involved in Construction 4.0 include "Digital," "Intelligent," "BIM," "Big Data," "Internet," "5G," "Internet of Things," "Blockchain," "AI," "AR," "VR," "3D printing," "digital transformation," "smart construction," "industrial Internet," "artificial intelligence," "cloud computing," and "smart construction site."

This study uses the ratio of the frequency of keywords in the current year to the total frequency of keywords of all firms in this year as a measure [45]. The specific calculation is as formula (1). Among them, $\text{keyword}_{i,\ t}$ represents the frequency of the keywords of the i-th firm in the t-th year, and totalkeyword_t represents the total frequency of the keywords of all firms. After the above calculations, the value range of Construction 4.0 is between 0 and 1, and firms with a value of 0 hardly use Construction 4.0.

$$C4_{i,j} = \frac{\text{keyword}_{i,t}}{\text{total keyword}_t}. \tag{1}$$

3.2.3. Mediating Variable. In order to comprehensively evaluate the technological innovation ability, this study adopts the comprehensive index evaluation method, selects the technical ratio of R&D personnel, the proportion of employees with a bachelor's degree or above, the number of patents in the current year, and the R&D investment intensity to measure the technological innovation capability of firms, and uses the principal component analysis method to calculate the composite score of the technological innovation capability of construction firms. The comprehensive measurement index of technological innovation capability is shown in Table 1.

First, the kmo and Bartlett tests were performed on the sample data, where the p value of the Bartlett test was 0.000, the chi-square value was 82.43, and the kmo value was 0.597, which was greater than 0.5. In line with the conditions of factor analysis; this study uses principal component analysis to extract common factors whose eigenvalues are greater than 1. The results show that the cumulative contribution rate of the first two principal component factors has reached 71.34%, retaining most of the information, so the first two factors are retained. Then, based on the scoring coefficients of the two factors, the following molecular scoring function is derived:

$$\begin{aligned} F_1 &= 0.353X_1 + 0.447X_2 + 0.251X_3 + 0.401X_4, \\ F_2 &= -0.546X_1 + 0.124X_2 + 0.795X_3 - 0.156X_4. \end{aligned} \tag{2}$$

Finally, according to the variance contribution of the two principal components, the comprehensive score of technological innovation capability is calculated as follows:

$$F = 0.639F_1 + 0.361F_2. \tag{3}$$

In order to exclude the influence of other factors, this paper controls the firm's age (Age), management expense contribution (Cme), asset-liability ratio (Lev), and total asset turnover (Ttc).

The specific variable definitions are shown in Table 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:

$$\text{ROE} = \alpha_1 C4 + \alpha_2 \text{Age} + \alpha_3 \text{Lev} + \alpha_4 \text{Cme} + \alpha_5 \text{Ttc} + \varepsilon, \tag{4}$$

$$\text{Inf} = \beta_1 C4 + \beta_2 \text{Age} + \beta_3 \text{Lev} + \beta_4 \text{Cme} + \beta_5 \text{Ttc} + \varepsilon, \tag{5}$$

$$\text{ROE} = Y_1 C4 + Y_2 \text{Inf} + Y_2 \text{Age} + Y_4 \text{Lev} + Y_5 \text{Cme} + Y_6 \text{Ttc} + \varepsilon. \tag{6}$$

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

Table 2: Definition of variables.

	Variables	Variable symbol	Description
Dependent variable	Firm performance	ROE	Return on equity
Independent variable	Construction 4.0	C4	Sourced from text mining
Mediating variable	Technological innovation capability	Inf	Index of technological innovation capability
Control variables	Company age	Age	The natural logarithm of the year the company was founded
	Debt asset ratio	Lev	Total liabilities/total assets
	Contribution of management expenses	Cme	Main business income/administrative expenses
	Total assets turnover	Ttc	Net profit/total average assets

Table 3: Descriptive statistics.

Variable	*N*	Mean	Median	Standard deviation	Min	Max
ROE	168	8.649	8.925	4.615	−4.260	26.40
C4	168	0.031	0.019	0.035	0	0.194
Inf	168	0.000	−0.158	0.734	−1.004	3.759
Age	168	2.995	3.091	0.347	1.946	3.664
Lev	168	74.126	76.935	11.547	41.28	92.22
Cme	168	38.98	33.92	47.49	2.539	606.4
Ttc	168	0.559	0.527	0.223	0.177	1.222

Table 4: Correlation analysis.

	ROE	C4	Inf	Age	Lev	Cme	Ttc
ROE	1						
C4	0.301***	1					
Inf	0.390***	0.286***	1				
Age	−0.065	0.075	−0.104	1			
Lev	0.232***	0.008	0.014	-0.155**	1		
Cme	0.089	−0.061	0.028	0.064	−0.001	1	
Ttc	0.433***	0.067	0.262***	−0.255***	0.346***	0.098	1

Note: $^{*}p < 0.10$; $^{**}p < 0.05$; and $^{***}p < 0.01$.

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. This shows that the firm application of Construction 4.0 technologies can achieve higher 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

Table 5: Regression analysis results.

	Model 1 ROE	Model 2 Inf	Model 3 ROE
C4	36.859***	5.920***	27.630***
	(−3.95)	(−3.28)	(−2.81)
Inf			1.559***
			(−3.99)
Age	0.314	−0.165	0.571
	(−0.41)	(−0.80)	(−0.83)
Lev	0.036	−0.006	0.046
	(−1.24)	(−1.47)	(−1.61)
Cme	0.005	0.001	0.004
	(−0.95)	(−1.36	(−0.81)
Ttc	7.936***	0.829***	6.643***
	(−4.36)	(−3.00)	(−3.78)
Constant	−0.77	0.27	−1.191
	(−0.23)	−0.35	(−0.38)
N	168	168	168
R^2	0.273	0.154	0.325
F	10.79	5.602	15.81

Note. T statistic in parentheses.

Table 6: Regression analysis results.

	Model 1 ROA	Model 2 Inf	Model 3 ROA
C4	11.616***	5.920***	9.586***
	(4.03)	(3.82)	(3.24)
Inf			0.343**
			(2.39)
Age	0.138	−0.165	0.195
	(0.46)	(−1.03)	(0.66)
Lev	−0.059***	−0.006	0.057***
	(−6.39)	(−1.22)	(−6.22)
Cme	0.001	0.001	0.001
	(0.64)	(0.58)	(0.54)
Ttc	1.885***	0.829***	1.601***
	(3.89)	(3.18)	(3.25)
Constant	4.488***	0.270	4.395***
	(3.78)	(0.42)	(3.75)
N	168	168	168
R^2	0.283	0.154	0.307
F	12.77	5.888	11.90

Note. T statistic in parentheses.

4.0 enables construction firms to improve productivity, reduce project delays and cost overruns, and improve safety, quality, and resource efficiency, leading to better firm performance. Different from the research results of Hajli et al. [35], the possible reason is that the digitalization process of China firms is advancing rapidly [79], and they have tasted the digital dividend in the development of the digital economy [80]. In addition, technical capabilities complement digital capabilities, which further promotes the positive impact of Construction 4.0 on firm performance [37]. Second, there is a significant positive correlation between technological innovation capability and firm performance, which is similar to the studies of Liu and Cheng [81] and Lu and Zhang [82], indicating that firms with a high level of technological innovation are more likely to achieve considerable performance. Third, there is a significant positive correlation between Construction 4.0 and technological innovation capabilities. The results are consistent with Liu et al. [60] and Xu [61]. Firms applying Construction 4.0 can better engage in social interaction, knowledge sharing, and coordinated practice with stakeholders, thereby promoting their technological innovation capabilities. Fourth, in the process of Construction 4.0 to promote firm performance, technological innovation capability plays a positive mediating role. This is consistent with Khin and Ho [38] view that if a firm wants to make full use of digital technology, 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, 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.

7.2. Practical Implications. This study provides the following implications for managers of listed construction firms on digital construction and technological innovation to improve firm performance: First, pay attention to digital construction and actively develop new technologies. Construction 4.0 has great potential to improve productivity and profit margins. Firms should increase the integration of new technologies such as BIM, big data, blockchain, 5G, cloud computing, and the Internet of Things in the whole process of construction and transform the production methods of construction firms, adjust and optimize the industrial structure, and accelerate the digital transformation of firms.

Second, integrate and coordinate the construction industry value chain and build a technological innovation network. Firms should integrate and coordinate two or more members, such as the construction party, the designer, and the operator, to jointly carry out collaborative innovation of the construction supply chain and to share knowledge, plan, and implementing together in the research and development work. Firms should actively participate in innovation activities, learn from each other with firms in the construction supply chain, discover new opportunities and acquire new knowledge in the process of learning, and realize knowledge integration and reorganization through mutual exchange to solve important problems and problems in construction projects.

Third, increase investment in R&D and maintain high-level innovation. Firms should attach importance to the cultivation and improvement of technological innovation capabilities, increase the level of R&D investment, and cooperate with universities and relevant talents in the field of digital technology to enhance scientific research strength, strengthen scientific research teams, and accelerate the speed of digital innovation.

Fourth, improve the digital transformation policy system of construction firms. The government should fully consider the production characteristics and development needs of construction firms, formulate digital policies and precise digital solutions unique to the construction industry, and promote digital transformation of construction firms.

8. Limitations and Future Research Directions

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 organization, 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.

Acknowledgments

This research was funded by 2021 Heilongjiang Province Philosophy and Social Science Research Planning Project: Relationship between innovation ability and performance of construction industry in Heilongjiang Province under the digital construction mode (Grant no. 21GLB063).

References

[1] J. Wang, D. Li, and X. Wu, "An empirical analysis of the status and role of China's construction industry as a pillar industry," *Construction Economy*, vol. 41, no. 12, pp. 5–8, 2020.

[2] L. Wang, "The application of BIM technology in cost control of engineering project construction," *Construction Economy*, vol. 41, no. 12, pp. 69–73, 2020.

[3] M. D. Hossain and A. Nadeem, "TOWARDS DIGITIZING the CONSTRUCTION INDUSTRY: STATE of the ART of CONSTRUCTION 4.0," in *Proceedings of the International Structural Engineering and Construction*, p. 184, Chicago, IL, USA, May 2019.

[4] De-G. J. Opoku, S. Perera, R. Osei-Kyei, and M. Rashidi, "Digital twin application in the construction industry: a literature review," *Journal of Building Engineering*, vol. 40, no. 2021, Article ID 102726.

[5] B. Manzoor, I. Othman, and J. C. Pomares, "Digital technologies in the architecture, engineering and construction (AEC) industry—a bibliometric—qualitative literature review of research activities," *International Journal of Environmental Research and Public Health*, vol. 18, no. 11, p. 6135, 2021.

[6] H. Liu, J. Song, and G. Wang, "A scientometric review of smart construction site in construction engineering and management: analysis and visualization," *Sustainability*, vol. 13, no. 16, p. 8860.

[7] K. Kim, G. Lee, and S. Kim, "A study on the application of blockchain technology in the construction industry," *KSCE Journal of Civil Engineering*, vol. 24, no. 9, pp. 2561–2571, 2020.

[8] U. Awan, R. Sroufe, and M. Shahbaz, "Industry 4.0 and the circular economy: a literature review and recommendations for future research," *Business Strategy and the Environment*, vol. 30, no. 4, pp. 2038–2060.

[9] P. Schönbeck, M. Lofsjogard, and A. Ansell, "Quantitative review of construction 4.0 technology presence in construction project research," *Buildings*, vol. 10, p. 173, 2020.

[10] F. Craveiro, J. P. Duarte, H. Bartolo, and P. J. Bartolo, "Additive manufacturing as an enabling technology for digital construction: a perspective on Construction 4.0," *Automation in Construction*, vol. 103, pp. 251–267, 2019.

[11] S. Perera, S. Nanayakkara, M. Rodrigo, S. Senaratne, and R. Weinand, "Blockchain technology: is it hype or real in the construction industry?" *Journal of Industrial Information Integration*, vol. 17, Article ID 100125, 2020.

[12] E. Forcael, I. Ferrari, A. Opazo-Vega, and J. A. Pulido-Arcas, "Construction 4.0: a literature review," *Sustainability*, vol. 12, no. 22, p. 9755.

[13] Z. You and L. Feng, "Integration of industry 4.0 related technologies in construction industry: a framework of cyber-physical system," *IEEE Access*, vol. 8, pp. 122908–122922, 2020.

[14] M. . Kozlovská, D. Klosova, and Z. Strukova, "Impact of industry 4.0 platform on the formation of construction 4.0 concept: a literature review," *Sustainability*, vol. 13, no. 5, p. 2683.

[15] L. Stojanovska-Georgievska, I. Sandeva, A. Krleski et al., "BIM in the center of digital transformation of the construction sector—the status of BIM adoption in north Macedonia," *Buildings*, vol. 12, no. 2, p. 218.

[16] S. P. Kumar, R. D. Raut, P. Priyadarshinee, S. K. Mangla, U. Awan, and B. E. Narkhede, "The Impact of IoT on the Performance of Vaccine Supply Chain Distribution in the COVID-19 Context," *IEEE Transactions on Engineering Management*, pp. 1–11, 2022.

[17] B. Qi, M. Razkenari, J. Li, A. Costin, C. Kibert, and S. Qian, "Investigating U.S. Industry practitioners' perspectives towards the adoption of emerging technologies in industrialized construction," *Buildings*, vol. 10, no. 5, p. 85, 2020.

[18] Ya Cheng, U. Awan, S. Ahmad, and Z. Tan, "How do technological innovation and fiscal decentralization affect the environment? A story of the fourth industrial revolution and sustainable growth," *Technological Forecasting and Social Change*, vol. 162, Article ID 120398, 2021.

[19] C. J. Turner, J. Oyekan, L. Stergioulas, and D. Griffin, "Utilizing industry 4.0 on the construction site: challenges and opportunities," *IEEE Transactions on Industrial Informatics*, vol. 17, no. 2, pp. 746–756.

[20] D. Aghimien, C. Aigbavboa, A. Oke, W. Thwala, and P. Moripe, "Digitalization of construction organisations – a case for digital partnering," *International Journal of Construction Management*, vol. 22, pp. 1950–1959, 2020.

[21] J. M. Davila Delgado, L. Oyedele, T. Beach, and P. Demian, "Augmented and virtual reality in construction: drivers and limitations for industry adoption," *Journal of Construction Engineering and Management*, vol. 146, no. 7, Article ID 04020079, 2020.

[22] H. Begić and M. Galić, "A systematic review of construction 4.0 in the context of the BIM 4.0 premise," *Buildings*, vol. 11, no. 8, p. 337.

[23] G. Shen and Z. Yuan, "The effect of enterprise internetization on the innovation and export of Chinese enterprises," *Economic Research Journal*, vol. 55, no. 01, pp. 33–48, 2020.

[24] F. Wu, H. Hu, H. Lin, and X. Ren, "Enterprise digital transformation and capital market performance: empirical evidence from stock liquidity," *Management World*, vol. 37, no. 07, 2021.

[25] H. Qi, X. Cao, and Y. Liu, "The influence of digital economy on corporate governance: analyzed from information asymmetry and irrational behavior perspective," *Reforma*, no. 04, pp. 50–64, 2020.

[26] H. Zhao, W. Wang, and X. Li, "How does digital transformation affect the total factor productivity of enterprises?" *Finance & Trade Economics*, vol. 42, no. 07, pp. 114–129, 2021.

[27] Y. Zhang, X. Li, and M. Xing, "Enterprise Digital Transformation and Audit Pricing," *Auditing Research*, vol. 03, pp. 62–71, 2021.

[28] M. Fakhar Manesh, M. M. Pellegrini, G. Marzi, and M. Dabic, "Knowledge management in the fourth industrial revolution: mapping the literature and scoping future avenues," *IEEE Transactions on Engineering Management*, vol. 68, no. 1, pp. 289–300.

[29] T. Hess, C. Matt, A. Benlian, and F. Wiesböck, "Options for formulating a digital transformation strategy," *MIS Quarterly Executive*, vol. 15, pp. 123–139, 2016.

[30] F. Ciampi, S. Demi, A. Magrini, G. Marzi, and A. Papa, "Exploring the impact of big data analytics capabilities on business model innovation: the mediating role of entrepreneurial orientation," *Journal of Business Research*, vol. 123, no. 2021, pp. 1–13.

[31] J. K. Nwankpa and P. M. Datta, "Balancing exploration and exploitation of IT resources: the influence of Digital Business Intensity on perceived organizational performance," *European Journal of Information Systems*, vol. 26, no. 5, pp. 469–488, 2017.

[32] M. Li and S. Jia, "Resource orchestration for innovation: the dual role of information technology," *Technology Analysis & Strategic Management*, vol. 30, no. 10, pp. 1136–1147, 2018.

[33] Y. U. Jiang, Q.-shi Meng, Y. Zhang, Xi Zhang, and F. Chen, "Digital innovation: exploration and enlightenment of the new perspective of innovation research," *Studies in Science of Science*, vol. 36, no. 07, pp. 1103–1111, 2021.

[34] Y. Qi and C. Cai, "Research on the multiple effects of digitalization on the performance of manufacturing enterprises and its mechanism," *Study & Exploration*, vol. 07, pp. 108–119, 2020.

[35] M. Hajli, J. M. Sims, and V. Ibragimov, "Information technology (IT) productivity paradox in the 21st century," *International Journal of Productivity and Performance Management*, vol. 64, no. 4, pp. 457–478, 2015.

[36] A. Usai, F. Fiano, A. Messeni Petruzzelli, P. Paoloni, M. Farina Briamonte, and B. Orlando, "Unveiling the impact of the adoption of digital technologies on firms' innovation performance," *Journal of Business Research*, vol. 133, pp. 327–336, 2021.

[37] J. Heredia, M. Castillo-Vergara, C. Geldes, F. M. Carbajal Gamarra, A. Flores, and W. Heredia, "How do digital capabilities affect firm performance? The mediating role of technological capabilities in the "new normal"" *Journal of Innovation & Knowledge*, vol. 7, no. 2, Article ID 100171.

[38] S. Khin and T. Cf Ho, "Digital technology, digital capability and organizational performance," *International Journal of Innovation Science*, vol. 11, no. 2, pp. 177–195, 2019.

[39] R. Maskuriy, A. Selamat, K. N. Ali, P. Maresova, and O. Krejcar, "Industry 4.0 for the construction industry—how ready is the industry?" *Applied Sciences*, vol. 9, no. 14, p. 2819, 2019.

[40] A. Lekan, A. Clinton, and J. Owolabi, "The disruptive adaptations of construction 4.0 and industry 4.0 as a pathway to a sustainable innovation and inclusive industrial technological development," *Buildings*, vol. 11, no. 3, p. 79, 2021.

[41] M. Wang, C. C. Wang, S. Sepasgozar, and S. Zlatanova, "A systematic review of digital technology adoption in off-site construction: current status and future direction towards industry 4.0," *Buildings*, vol. 10, no. 11, p. 204, 2020.

[42] A. Karmakar and V. S. K. Delhi, "Construction 4.0: what we know and where we are headed?" *Journal of Information Technology in Construction*, vol. 26, no. 2021, pp. 526–545.

[43] N. Kawęcki, *Organizing for Innovation in a Digitized World*, , pp. 1398–1408, Nowoczesne Systemy Zarządzania, 2021.

[44] Y. Liu, J. Dong, and W. Jiang, "Digital innovation management:theoretical framework and future research," *Management World*, vol. 36, no. 07, p. 198, 2020.

[45] B. Ren and G. U. O. Meng, "Research on digital level and operation performance based on text mining," *Journal of Statistics and Information*, vol. 33, no. 11, p. 128, 2017.

[46] C. Chen, Li Zhu, H. Zhong, C. Liu, M. Wu, and H. Zeng, "Practical innovation of Chinese enterprises from "digital survival" view," *Journal of Management Sciences in China*, vol. 22, no. 10, pp. 1–8, 2019.

[47] H. E. Fan and H. Liu, "The performance improvement effect of digital transformation enterprises from the digital economy perspective," *Reforma*, no. 04, pp. 137–148, 2019.

[48] F. Liu, "How digital transformation improve manufacturing's productivity: based on three influencing mechanisms of digital transformation," *Finance and Economics*, vol. 10, pp. 93–107, 2020.

[49] V. Jafari Sadeghi and P. P. Biancone, "How micro, small and medium-sized enterprises are driven outward the superior international trade performance? A multidimensional study on Italian food sector," *Research in International Business and Finance*, vol. 45, pp. 597–606, 2018.

[50] C. L. Wang and P. K. Ahmed, "Dynamic capabilities: a review and research agenda," *International Journal of Management Reviews*, vol. 9, no. 1, pp. 31–51, 2007.

[51] A. Malhotra, A. Mathur, S. Diddi, and A. D. Sagar, "Building institutional capacity for addressing climate and sustainable development goals: achieving energy efficiency in India," *Climate Policy*, vol. 22, no. 5, pp. 652–670, 2022.

[52] W. S. DeSarbo, C. Anthony Di Benedetto, Michael Song, and I. Sinha, "Revisiting the miles and snow strategic framework: uncovering interrelationships between strategic types, capabilities, environmental uncertainty, and firm performance," *Strategic Management Journal*, vol. 26, no. 1, pp. 47–74, 2005.

[53] X. Zhang, "Wu junjun, "government R&D funding intensity, enterprise R&D capability and innovation performance——based on empirical evidence of GEM listed companies," *Science & Technology Progress and Policy*, vol. 31, no. 22, pp. 7–13, 2014.

[54] U. Awan, *Steering for Sustainable Development Goals: A Typology of Sustainable Innovation*, 2020.
[55] J. Chen, S. Huang, and Y. Liu, "Operations management in the digitization era: from empowering to enabling," *Management World*, vol. 36, no. 02, p. 117, 2020.
[56] G. Vial, "Understanding digital transformation: a review and a research agenda," *The Journal of Strategic Information Systems*, vol. 28, no. 2, pp. 118–144, 2019.
[57] J. Qian and Y. He, "Dynamic capability evolution and digital transformation of traditional enterprise," *China Soft Science*, vol. 41, no. 06, pp. 135–143, 2021.
[58] S. Nambisan, "Digital entrepreneurship: toward a digital technology perspective of entrepreneurship," *Entrepreneurship: Theory and Practice*, vol. 41, no. 6, pp. 1029–1055, 2017.
[59] L. Yi, F. Wu, and S. Xu, *Research on the Performance-Driven Effect of enterprise Digital Transformation*, Securities Market Herald, no. 08, Perth, Western Australia, 2021.
[60] S. Liu, M. Li, and S. Hu, "The influence mechanism of enterprise digitalization on technological innovation capability," *Modern Management Science*, no. 03, pp. 109–117, 2022.
[61] X. Xu, "Digital transformation and technological innovation of manufacturing enterprises," *Journal of Industrial Technological Economics*, vol. 41, no. 6, pp. 18–25, 2022.
[62] Y. Cai, "STI governance and digital transformation under the leadership of the communist party of China: from the perspective of building & improving a new type of data-driven national system," *Management World*, vol. 37, no. 08, pp. 30–46, 2021.
[63] H. Cong, D. Zou, and F. Wu, "Influence mechanism of multi-network embeddedness to enterprises innovation performance based on knowledge management perspective," *Cluster Computing*, vol. 20, no. 1, pp. 93–108, 2017.
[64] P. van Hemert, P. Nijkamp, and E. Masurel, "From innovation to commercialization through networks and agglomerations: analysis of sources of innovation, innovation capabilities and performance of Dutch SMEs," *The Annals of Regional Science*, vol. 50, no. 2, pp. 425–452, 2013.
[65] X.. Shen, "Has financial marketization reform promoted innovation? — an empirical test based on mediation effect," *Open Journal of Social Sciences*, vol. 07, no. 04, pp. 160–177, 2019.
[66] U. Awan, A. Kraslawski, and J. Huiskonen, "The impact of relational governance on performance improvement in export manufacturing firms," *Journal of Industrial Engineering and Management*, vol. 11, no. 3, pp. 349–370, 2018.
[67] P. E. Murphy and B. B. Schlegelmilch, "Corporate social responsibility and corporate social irresponsibility: introduction to a special topic section," *Journal of Business Research*, vol. 66, no. 10, pp. 1807–1813, 2013.
[68] S. Liu and S. Yang, "Research on the influence of technological innovation capability on enterprise performance——based on the moderating effect of executives' shareholding and the intensity of board meetings," *Communication of Finance and Accounting*, vol. 33, p. 43, 2019.
[69] C. Shan, W. Zhong, and L. Zhang, "An empirical study on the impact of SMEs' technological innovation to enterprise performance: enterprise growth and education level of staff as moderating variable," *On Economic Problems*, vol. 10, pp. 66–73, 2017.
[70] C. Chen and Q. He, "Influence of R&D investment and supply chain concentration on seed enterprises' performance," *Journal of Hunan Agricultural University*, vol. 22, no. 04, pp. 86–92, 2021.
[71] X. Li and G. Chen, "Research on the relationship between information technology input, technological innovation dynamic capabilities and enterprise performance," *Science & Technology Progress and Policy*, vol. 36, no. 16, pp. 100–107, 2019.
[72] Xu, Shang, Yu, and Liu, "Intellectual capital, technological innovation and firm performance: evidence from China's manufacturing sector," *Sustainability*, vol. 11, no. 19, p. 5328, 2019.
[73] H. S. Lee, S. Y. Lee, W. M. Har, and S. Yap, "Financial Sustainability of the Construction Firms towards the Era of Industrial Revolution 4.0: The Role of Technological Innovation," in *Proceedings of the 2020 IEEE 8th R10 Humanitarian Technology Conference (R10-HTC)*, pp. 1–6, Kuching, Malaysia, December 2020.
[74] Q. Li and J. Shi, "Dam construction 4.0," *Journal of Hydroelectric Engineering*, vol. 34, no. 08, pp. 1–6, 2015.
[75] Le Lin and D. Xie, "Do analysts 'recommendation revisions use management tones? A textual analysis based on earnings communication conferences," *Management World*, vol. 33, no. 11, p. 128, 2017.
[76] Z. Wen, L. Chang, H. Kit-Tai, and L. Hongyun, "Testing and application of the mediating effects," *Acta Psychology Sinica*, vol. 37, no. 05, pp. 614–620, 2004.
[77] B. García de Soto, I. Agusti-Juan, J. Hunhevicz et al., "Productivity of digital fabrication in construction: cost and time analysis of a robotically built wall," *Automation in Construction*, vol. 92, pp. 297–311, 2018.
[78] S. H. Ghaffar, J. Corker, and M. Fan, "Additive manufacturing technology and its implementation in construction as an eco-innovative solution," *Automation in Construction*, vol. 93, pp. 1–11, 2018.
[79] L. I. Qi, L. Liu, and J. Shao, "The effects of digital transformation and supply chain integration on firm performance: the moderating role of entrepreneurship," *Economics and Management*, vol. 43, no. 10, pp. 5–23, 2021.
[80] S. Liu, J. Yan, S. Zhang, and H. Lin, "Can corporate digital transformation promote input-output efficiency?" *Management World*, vol. 37, no. 05, 2021.
[81] Z. Liu and H. Cheng, "Degree of internationalization, technological innovation capability and company performance——based on empirical evidence of listed companies in strategic emerging industries," *Finance and Accounting Monthly*, vol. 08, pp. 81–88, 2019.
[82] X. Lu and X. Zhang, "Informatization Capital, Technological Innovation Capability and Enterprise Performance," *Friends of accounting*, vol. 09, pp. 64–70, 2021.
[83] J. Lee, B. Bagheri, and H. A. Kao, "A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems," *Manufacturing letters*, vol. 3, pp. 18–23, 2015.
[84] C. Wang, "Research on the effecting mechanism of digital transformation on corporation innovation performance," *Contemporary Economic Management*, vol. 43, no. 03, pp. 34–42, 2021.
[85] T. D. Oesterreich and F. Teuteberg, "Understanding the implications of digitisation and automation in the context of Industry 4.0: a triangulation approach and elements of a research agenda for the construction industry," *Computers in Industry*, vol. 83, pp. 121–139, 2016.
[86] U. Awan, A. Kraslawski, and J. Huiskonen, "Governing interfirm relationships for social sustainability: the relationship between governance mechanisms, sustainable collaboration, and cultural intelligence," *Sustainability*, vol. 10, no. 12, p. 4473, 2018.

[87] O. Nagy, I. Papp, and R. Z. Szabo, "Construction 4.0 organisational level challenges and solutions," *Sustainability*, vol. 13, no. 21, Article ID 12321, 2021.

[88] O. Alhawari, U. Awan, M. K. S. Bhutta, and M. A. Ulku, "Insights from circular economy literature: a review of extant definitions and unravelling paths to future research," *Sustainability*, vol. 13, no. 2, p. 859.

[89] F. A. Emuze, L. Wentzel, and J. J. Smallwood, "Improving the business trajectory among small and medium size construction firms in South Africa," *Journal of Construction Project Management and Innovation*, vol. 6, no. 2, pp. 1477–1487, 2016.

[90] M. Schuld, I. Sinayskiy, and F. Petruccione, "An introduction to quantum machine learning," *Contemporary Physics*, vol. 56, no. 2, pp. 172–185, 2014.

[91] S. S. Gill, A. Kumar, H. Singh et al., "Quantum computing: a taxonomy, systematic review and future directions," *Software: Practice and Experience*, vol. 52, no. 1, pp. 66–114.

[92] U. Awan, L. Hannola, A. Tandon, R. K. Goyal, and A. Dhir, "Quantum computing challenges in the software industry. A fuzzy AHP-based approach," *Information and Software Technology*, vol. 147, Article ID 106896, 2022.

[93] M. Bhavin, S. Tanwar, N. Sharma, S. Tyagi, and N. Kumar, "Blockchain and quantum blind signature-based hybrid scheme for healthcare 5.0 applications," *Journal of Information Security and Applications*, vol. 56, Article ID 102673, 2021.

[94] A. Ajagekar and F. You, "Quantum Computing for Energy Systems Optimization: Challenges and Opportunities," *Energy*, vol. 179, pp. 76–89, 2019.