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Digital Transformation in the Chinese Construction Industry: Status, Barriers, and Impact

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Abstract: Digital transformation is the direction that the Chinese construction industry is moving toward. This paper aims to investigate its current status, major barriers, and potential impact. To achieve this goal, a questionnaire survey was carried out. The results show that 80% of enterprises where the industry experts work have already formulated digital transformation plans or made plans. Additionally, BIM software was the most commonly used digital technology. Furthermore, "Data Fragmentation", "Lack of Core Technology", "Weak Digital Infrastructure Allocation", "Lack of Technical Personnel", and "Lack of Technical Standards" were prominent barriers. Moreover, digital transformation was perceived to affect the procurement management mostly at a project level, and to affect the governance performance mostly at an enterprise level. These findings can provide scholars and practitioners with an in-depth understanding of digital transformation in the Chinese construction industry. They might also help policymakers formulate appropriate policies to promote digital transformation.

Keywords: digital transformation; the Chinese construction industry; major barriers; potential impact

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1. Introduction

The construction industry is one of the key pillars of the Chinese economy. According to the National Bureau of Statistics of China (2022), the output value of the construction industry in 2021 reached 8013.85 billion RMB, accounting for about 7% of the overall gross domestic product. However, its profit ratio of production was only 2.9%, far lower than manufacturing (6.8%) [1]. Transformation and upgrading is an important strategy for the construction industry to improve its economic benefits and core competitiveness [2]. However, there are many problems in the construction industry, such as insufficient new driving forces for development, lagging technological innovation, and low levels of standardization.

Fortunately, the Fourth Industrial Revolution (4IR) brought smart technologies, which can potentially enhance the performance of the construction industry in different ways [3]. China's 14th Five-Year Plan clearly proposes to promote digital industrialization and industrial digitization, and to simulate the deep integration of the digital economy and the real economy. The general trend is to promote the deep integration of new technologies, such as technologies for big data processing, cloud computing, technologies for Building Information Model (BIM), Virtual Reality (VR), and Artificial Intelligence (AI) within the construction industry [4], thereby accelerating the digital transformation of the construction industry.

However, digital transformation is a long term and sustainable process [4], and the environment of construction projects is changeable and complex [5]. The construction industry faces endless difficulties in the process of digital transformation, such as lack of core technology [6], poor financing ability [2], insufficient data volume [7] and so on. According to the China Industry Information Network, the proportion of construction digital investment in the total output value is only 0.10%, which is lower than the international average of 0.30%. The IDC briefing (2020) shows that 64% of construction enterprises are in urgent need of digital transformation, and only 8% of enterprises have completed digital transformation [8]. For achieving successful digital transformation in the Chinese construction industry, there is a need to investigate its current status, major barriers, and potential impact, which has not been conducted in the existing studies.

The objectives of this study are to (1) investigate the current status of digital transformation in the Chinese construction industry; (2) explore major barriers obstructing the process of digital transformation; and (3) evaluate the potential impact of digital transformation on project performance and construction enterprise performance. This study would reveal the current status, major barriers, and potential impact of digital transformation in the Chinese construction industry to bridge the knowledge gap in previous studies. Moreover, this research would provide reference to policymakers to formulate appropriate policies, and it would provide practitioners with an in depth understanding of digital transformation in the Chinese construction industry.

2. Literature Review

2.1. Digital Transformation in the Construction Industry

Digital transformation is a multidisciplinary issue, involving strategy management, information technology, organization behavior, supply chains management, etc. [4]. From the hard aspect, digital transformation is defined as a process that aims to improve an entity by triggering significant changes to its properties through digital technologies [9]. From the soft aspect, digital transformation is more a managerial issue than a technical one [10]. Successful digital transformation demands evolution or the creation of a business model that is precipitated by digital technologies [11–13]. This paper defined digital transformation as the structural transformation of the enterprise development mode and the physical form that are driven by digital technologies and by data elements, covering field environmental monitoring, intelligent scheduling, material supervision, digital delivery, and other aspects.

There are three stages for achieving digital transformation. They are digitization, digitalization, and digital transformation [4]. Digitization reflects the transformation of professions through computerization (e.g., the integration of digital technology with existing tasks) [14]. Digitalization describes the changes wrought in business processes by the implementation of digital technologies [15]. Digital transformation describes the development of new business models [16].

Many digital technologies would support the digital transformation of the construction industry. For example, cyber-physical systems (CPS) can be used as a bi-directional link between virtual models and their real counterparts on-site [17]. Artificial intelligence (AI) would be helpful for resource and waste optimization, supply chain management, safety management, contract management, etc. [18]. BIM software can help stakeholders to make a decision and improve the process of construction and delivery [19]. In summary, digital technologies can be divided into three categories, i.e., internet technologies, analytical technologies, and mobile technologies [12]. They can be used for data visualization, data acquisition, data analytics, communication, and construction automation [20]. From the literature review, 14 digital technologies used in the construction industry were identified, and they are shown in Table 1.

Table 1. The potential digital technologies adopted in the construction industry.

Digital Technology	Application	Reference
CPS	Data visualization	[17,21]
Internet of things (IoTs)	Data acquisition	[20–22]
Cloud computing	Data analytics	[21]
Blockchain	Communication	[21,23]
3D printing	Construction automation	[20,21]

Table 1. *Cont.*

Digital Technology	Application	Reference
Big data	Data analytics	[20,21,24]
Augmented Reality (AR)	Data acquisition	[20,21]
AI	Data analytics	[18,20,21]
Automatic mechanical equipment	Construction automation	[20,21]
Network security technology	Communication	[25,26]
Real-time monitoring platform	Data acquisition	[21,27]
BIM software	Data visualization; Data analytics; Data acquisition	[20,21,28]
Mobile technology	Communication	[20,21]
Others (e.g., GIS, Eye-tracking)	–	[20,21]

2.2. Barriers to Digital Transformation in the Construction Industry

Several studies have completed excellent work relevant to the barriers hindering digital transformation. Chien et al. (2014) emphasized the importance of data volume, data integration, technical standards, talents, benchmarks, and cognition [29]. Ahmed (2018) identified 37 barriers to BIM implementation in the construction industry [19]. Vial (2019) pointed out that inertia and resistance are two barriers to changing the value creation process [9]. Tripathi et al. (2019) discovered that organization culture, improper business cases, cybersecurity, and infrastructure are all key to industry 4.0 transformation [7]. Agrawal et al. (2019) proposed 12 barriers to the digital transformation of the supply chain [30]. Zhou et al. (2019) uncovered that organizational issues, insufficient government support, legal issues, resistance to change, high costs, and insufficient external motivation are prominent barriers to BIM adoption in China [31]. Jones et al. (2021) summarized that data insufficiency and unreliability, lack of core technology and talents, weak financing ability, lack of benchmarks, and lack of digital cognitive are all barriers to digital transformation in manufacturing [6]. Wang et al. (2022) proposed 26 barriers to digital transformation in the engineering and construction sectors [2]. By a comprehensive literature review, Table 2 summarized the 17 potential barriers to digital transformation in the Chinese construction industry.

Furthermore, previous studies proposed several frameworks to categorize the potential barriers to digital transformation. For example, Chowdhury et al. (2019) proposed six groups, i.e., technological barrier, organizational barrier, financial barrier, process barrier, psychological barrier, and government barrier [21]. Wu et al. (2021) classified barriers to BIM implantation into project stakeholder-related factors, financially-related factors, employee-related factors, factors related to external environment, and software-related factors [32]. Vogelsang et al. (2021) divided barriers to digital transformation into missing skills, technical barriers, individual barriers, organizational and cultural barriers, and environmental barriers [33]. Aditya et al. (2021) revealed nine categories for barriers to digital transformation in higher education. They are resistance to change, resources, vision, adaptability, skill and knowledge, leadership, technology, policy, and government and economic ones [34]. Ghobakhloo et al. (2022) used the Technology-Organization-Environment (TOE) framework to introduce barriers to industry 4.0 technology implementation [35].

This study adopted the TOE framework in order to explain the categories of barriers to digital transformation in the Chinese construction industry. The TOE framework was always used to describe influence factors of innovations in various industries, such as retail and manufacturing [36,37]. Previous studies have proved that this framework has a broad application and provides enough explanatory power across the organization level, firm level, industry level, and national level [35,36]. Under this framework, 17 barriers were packaged into three groups: environment related factors, technology related factors, and organization related factors.

Table 2. Potential barriers to digital transformation in the Chinese construction industry.

Category	Barriers	[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]	[K]	Total
Environment Related Factors	Insufficient Business Model Innovation		√	√						√		√	4
	Insufficient Data	√		√		√	√				√	√	6
	Inadequate Support from Government		√	√			√	√	√	√		√	7
	Lack of Demand from Owners for Digital Building Products		√	√	√							√	4
	Data Fragmentation	√	√	√	√		√			√	√	√	8
	Weak Digital Infrastructure Allocation		√	√	√		√	√					5
Technology Related Factors	Lack of Core Technology		√		√	√	√	√	√	√		√	8
	Lack of Technical Standards	√	√	√	√		√		√	√	√	√	9
	Poor Data Security				√		√	√	√	√	√	√	7
	Lack of Technical Personnel	√	√	√	√	√	√	√		√		√	9
	Backward Technology System		√		√			√	√		√		5
Organization Related Factors	Weak Financing Ability			√		√	√	√		√	√		6
	Pursuit for Low Cost		√	√	√				√	√	√	√	7
	Weak Cost Control Ability for Transformation			√			√				√		3
	Lack of Relevant Training		√	√	√						√		4
	Lack of Benchmarks	√	√			√	√						4
	Lack of Digital Cognitive	√	√	√	√	√	√	√	√	√		√	10

Note: [A] = Chien et al. (2014) [29]; [B] = Ahmed (2018) [19]; [C] = Wang et al. (2022) [2]; [D] = Wu et al. (2021) [32]; [E] = Jones et al. (2021) [6]; [F] = Tripathi et al. (2019) [7]; [G] = Aditya et al. (2021) [34]; [H] = Vogelsang et al. (2019) [33]; [I] = Agrawal et al. (2019) [30]; [J] = Ghobakhloo et al. (2022) [35]; [K] = Zhou et al. (2019) [31].

3. Methodology

Several steps were conducted in this study. Firstly, a literature review was carried out to extract knowledge about the potential barriers to digital transformation. A questionnaire was then designed to survey the status of digital transformation and its impact, and assess the relative importance of each barrier. Before the full-scale survey, five experts were asked to validate the questionnaire. Their profiles were presented in Table 3. After the pilot study, the questionnaire was distributed to target respondents. The mean score ranking and intergroup comparison among different respondents were then analyzed by using SPSS 25.0.

Table 3. The profiles of five experts.

No.	Organization	Designation	Work Experience	Familiar with Digital Transformation
Mr. A	Contractor	Project Manager	≥10 years	Yes
Mr. B	Contractor	Project Manager	≥15 years	Yes
Mr. C	University	Professor	≥20 years	Yes
Mr. D	Design firms	Designer	≥10 years	Yes
Mr. E	Contractor	Senior Engineer	≥20 years	Yes

The questionnaire contained four sub-sections. The first section was designed to collect respondents' basic information, including occupation, work experience, education experience, and the size and ownership of the enterprise where the industry expert works. The second section aimed to survey the current status of digital transformation in the Chinese construction industry. Section three asked respondents to rank the barriers for digital transformation on a five-point Likert scale. The fourth section collected opinions on the perceived potential performance improvement with the digital transformation. All respondents were requested to fill in all of the sections, depending on their knowledge and experience. Due to the digital transformation in construction industry involving many stakeholders, the target respondents include scholars, government personnel, and various types of industry experts, such as engineers, managers, designers, etc.

A total of 86 complete questionnaires were received. As shown in Table 4, the respondents belong to a variety of backgrounds with occupations involving engineers (23.26%), managers (41.86%), designers (1.16%), government personnel (2.33%), researchers (22.09%) and others (such as consultants, 9.30%). More than 97% of respondents are well educated with a Bachelor degree or above. About 70% of respondents have more than five years of work experience, which is beneficial due to raising the quality of the survey result. Table 1 also shows that 65 industry experts work in a variety of enterprises, including private enterprises, state-owned enterprises, and mixed-ownership enterprises, ranging in size from tiny to large.

Table 4. Respondents' profiles.

Category			Fre	Per
Occupation	Industry	Engineer	20	23.26%
		Manager	36	41.86%
		Designer	1	1.16%
		others	8	9.30%
		Total	65	75.58%
	Government	Government personnel	2	2.33%
	Academia	Researcher	19	22.09%
Education experience	Bachelor degree or below	Below undergraduate level	2	2.33%
		Bachelor degree	52	60.47%
	Master degree or above	Master degree	18	20.93%
		Doctoral degree	14	16.28%

Table 4. *Cont.*

Category		Fre	Per
Work experience	<5 years	25	29.07%
	5–10 years	34	39.53%
	11–15 years	17	19.77%
	16–20 years	4	4.65%
	>20 years	6	6.98%
The nature of ownership of the enterprise where the industry expert works	Private enterprises	22	33.85%
	State-owned enterprises	40	61.54%
	Mixed-ownership enterprises	3	4.62%
The size of the enterprise where the industry expert works	Large (OR or TA $\geq$ 800 million RMB)	33	50.77%
	Medium (60 $\leq$ OR $\leq$800 million RMB and 50 $\leq$ TA $\leq$ 800 million RMB)	17	26.15%
	Small (3 million RMB $\leq$ OR and TA $\leq$ 60 million RMB)	10	15.38%
	Tiny (OR or TA $\leq$ 3 million RMB)	5	7.69%
Total		86	100%

Note: OR means operation revenue. TA represents total assets.

The enterprise size is divided according to the construction enterprise classification standard issued by Ministry of Industry and Information Technology of China.

Various data analysis tools were used in this paper. First, the Shapiro–Wilk test was carried out to test the normality of the dataset, which is suitable for a small sample size [38]. If the data distribute normally, parametric tests should be used for further data analysis. Otherwise, nonparametric tests should be used in the following sections [39]. Second, the Cronbach alpha coefficient was devoted to test the reliability of the survey result. If the alpha is bigger than 0.7, it means the scale is reliable [40]. Third, the mean score ranking was conducted, which is regarded as the simplest tool to identify the relative importance of each barrier [5]. The One sample Wilcoxon signed rank test was then applied to examine if the median of the dataset equals that of the hypothesized value [41]. Finally, intergroup comparisons were carried out to test the respondents' perception consistency. The Kruskal–Wallis Test can be used to verify whether K (>2) independent samples come from the same distribution, whereas the Kolmogorov–Smirnov test can be used for intergroup comparison between two independent samples [42,43].

4. Data Analysis and Discussion

4.1. Status of Digital Transformation in the Chinese Construction Industry

To identify the status of digital transformation in the Chinese construction industry, the respondents were requested to present the status of their enterprises' digital strategy and choose the six most commonly used digital technologies. Table 5 shows that 80% of enterprises where the industry expert works have already formulated a digital transformation plan or else had plans being made. Furthermore, 10% of enterprises made short-term plans, and 25% of enterprises made medium or long-term plans. Given that digital transformation is still a new thing in the construction industry, the percentage of the 25% who already formulated medium or long-term plans is a bonus in value-adding the responses received.

Table 5. The status of enterprises' digital strategy.

Status	Frequency	Percentage
No plans have been made	13	20%
Plans are being made	30	45%
Short-term (1–2 year) plans have been made	6	10%
Medium or long-term (more than 3 years) plans have been made	16	25%

Figure 1 presents the status of digital technology applications in the Chinese construction industry. Among 14 digital technologies, the most commonly used technology was BIM software, which received 54 votes. Subsequently, big data (53 votes), real-time monitoring platform (39 votes), IoTs (38 votes), cloud computing (36 votes), and AI (such as machine learning, 30 votes) were listed. With the exception of other technologies (5 votes), the mobile technology became the least commonly used technology, with only 9 votes.

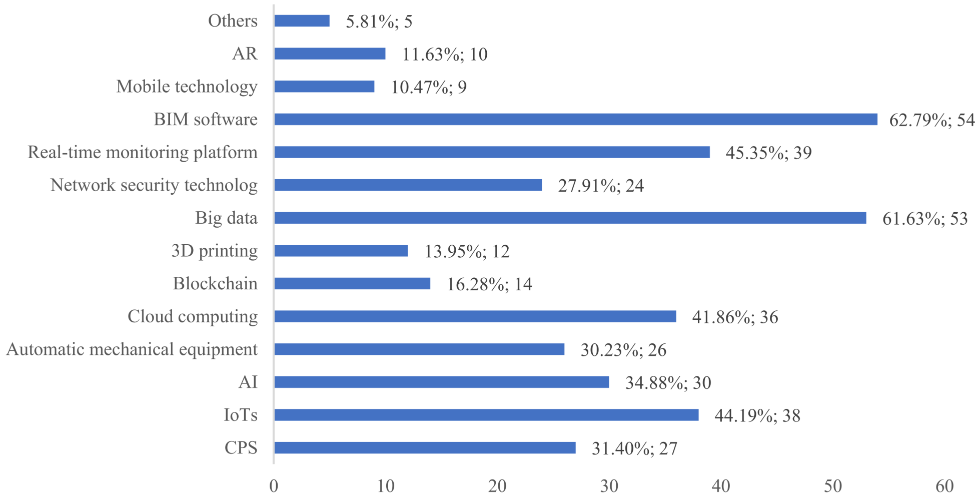

Figure 1. The status of digital technology application.

4.2. Barriers to Digital Transformation

Table 6 presents respondents' assessment of barriers and the relevant statistical test results. The Cronbach's Alpha of the dataset was 0.938, which is greater than 0.9, meaning that the dataset has good reliability [5]. Furthermore, the Cronbach's Alpha if Item Deleted for each barrier was smaller than 0.938, indicating that all variables should be kept [40]. The results of the Shapiro–Wilk test indicate that all of the barriers were significant at the significance level of 0.05, suggesting that the dataset were not normally distributed [39]. Therefore, a non-parametric test should be carried out in the next statistical analysis. One sample Wilcoxon signed rank test results demonstrate that all barriers were statistically equal to or greater than the test value of 3, indicating that all of the barriers have significant impacts on digital transformation [41].

The intergroup comparison results show that there were significant differences in the perception of barriers to digital transformation by respondents with different backgrounds. By respondents' work experience, the p-values of the Kruskal–Wallis test were larger than 0.05, suggesting that the perceptions of all barriers are unidimensional [43]. By respondents' designation, the barriers of "Data fragmentation" and "Lack of technical standards" were perceived differently, with p-values smaller than 0.05. By respondents' educational experience, the barrier of "Data fragmentation" had a statistically significant difference in the perceptions.

To identify the relative importance of barriers, mean values were calculated. Table 6 shows that all barriers received a mean score greater than 3. Among them, the barrier of "Data Fragmentation" received the highest score with a value of 3.930, followed by "Lack of Core Technology (mean value: 3.870)", "Weak Digital Infrastructure Allocation (mean value: 3.830)", "Lack of Technical Personnel (mean value: 3.800)", and "Lack of Technical Standards (mean value: 3.780)", whereas the barrier of "Inadequate Support from Government" was assessed as the least important variable, with a value of 3.430.

Table 6. Data analysis results.

Barriers	Mean	Rank	SD	Cronbach's Alpha If Item Deleted	*p* Value				
					Shapiro–Wilk Test	One Sample Wilcoxon Signed Rank Test	Kruskal–Wallis Test		Kolmogorov–Smirnov Test
							Designation	Work Experience	Education Experience
Data Fragmentation	3.930	1	0.823	0.936	0.000	0.000	0.000 *	0.397	0.014 *
Lack of Core Technology	3.870	2	0.700	0.934	0.000	0.000	0.307	0.497	1.000
Weak Digital Infrastructure Allocation	3.830	3	0.739	0.935	0.000	0.000	0.087	0.235	0.286
Lack of Technical Personnel	3.800	4	0.852	0.934	0.000	0.000	0.269	0.549	0.912
Lack of Technical Standards	3.780	5	0.817	0.932	0.000	0.000	0.018 *	0.873	0.062
Lack of Demand from Owners for Digital Building Products	3.770	6	0.890	0.935	0.000	0.000	0.298	0.932	0.650
Weak Cost Control Ability of Transformation	3.720	7	0.714	0.934	0.000	0.000	0.123	0.445	0.322
Lack of Benchmarks	3.710	8	0.780	0.934	0.000	0.000	0.078	0.807	0.291
Lack of Digital Cognitive	3.710	8	0.893	0.933	0.000	0.000	0.107	0.674	0.480
Insufficient Business Model Innovation	3.700	10	0.670	0.933	0.000	0.000	0.310	0.518	0.875
Pursuit for Low Cost	3.700	10	0.813	0.934	0.000	0.000	0.063	0.508	0.753
Insufficient Data	3.670	12	0.789	0.935	0.000	0.000	0.290	0.536	0.958
Backward Technology System	3.670	12	0.860	0.933	0.000	0.000	0.109	0.913	0.480
Weak Financing Ability	3.660	14	0.761	0.933	0.000	0.000	0.160	0.766	0.753
Poor Data Security	3.630	15	0.812	0.933	0.000	0.000	0.247	0.476	0.882
Lack of Relevant Training	3.570	16	0.805	0.935	0.000	0.000	0.484	0.749	0.998
Inadequate Support from Government	3.430	17	0.902	0.936	0.000	0.000	0.446	0.216	0.322

Note: * means that there is significantly statistical difference by intergroup comparison.

4.2.1. Data Fragmentation

Data fragmentation is the biggest barrier to digital transformation in the Chinese construction industry. The data existing in the construction industry can be divided into project data (such as quality, schedule, cost, etc.) [44], transaction data (such as bonds and stocks) [24], and public data (including government data and social data) [45]. These data are from project stakeholders with different specialties and scatter in various systems and platforms, resulting in the industrial chain data segmentation [46]. This hinders the construction industry's digital transformation from the following four aspects. First, data fragmentation can lead to a data gap in a construction project, making it difficult to understand the interactions between building materials, components, and systems [47]. Second, data fragmentation can lead to collaborative problems, such as conflicts and miscommunication between design and construction [48]. Third, data fragmentation makes it more difficult to share information between the different stages, hence leading to a low level of performance in terms of time, cost, and quality of construction projects [49]. Fourth, due to data fragmentation, data in construction projects is easy to be stolen or lost, which may pose a threat to security [18,50]. Given the above, data integration is an important barrier to digital transformation.

4.2.2. Lack of Core Technology

The realization of digital transformation relies on a variety of digital technologies to conduct data acquisition, analysis, visualization, communication, and automation [20]. Although construction sectors have introduced many advanced digital technologies, there are still challenges to applying them [29]. First, at the data collection stage, with present sensor technology, it is difficult to acquire a variety of data and to transfer it to a cloud server with high accuracy and speed [27]. Second, data security technology is lacking to ensure data privacy during data storage and processing [18,22]. Third, digital transformation depends on a variety of equipment and systems, so more reliable technology is needed to ensure its continuous operation and development [20]. Fourth, the application of AI faces a series of ethical problems, such as whether robots can have self-awareness, which need to be solved urgently [18]. The lack of core technology has limited the scope and speed of digital transformation, and it also increases the cost of digital transformation [20].

4.2.3. Weak Digital Infrastructure Allocation

Weak digital infrastructure allocation gained the third place in hindering digital transformation. Digital infrastructure includes communication infrastructure, data centers, electronic payment systems, etc., which is the cornerstone of digital transformation [51]. However, digital infrastructure is still weak in the Chinese construction industry [52]. Although BIM software has been widely applied in many large and medium-sized construction firms, other digital technologies, such as sensor technology, chips, and AI, still lags behind other industries [53,54]. Weak digital infrastructure allocation makes it difficult for digital technologies to be widely applied. Weak digital infrastructure allocation might also bring prominent security issues, such as data leakage and network attacks [55]. Therefore, it is necessary to attach importance to the construction and development of digital infrastructure and strengthen the basic support of digital transformation.

4.2.4. Lack of Technical Personnel

Lack of technical personnel is the fourth important obstacle to digital transformation in the Chinese construction industry. The achievement of digital transformation requires effort from various technical personnel, including data analysts, artificial intelligence and machine learning experts, software development engineers, and hardware engineers [12,56,57]. In addition, digital transformation also needs cross-domain talents, who can integrate knowledge and technology in different fields [58]. However, the penetration rate of digital skills in the construction sectors is still low, resulting in a serious shortage of digital talent [59]. The lack of technical personnel might influence the process of data collection, data governance, data analysis, and data utilization, thus impeding the progress of digital transformation.

4.2.5. Lack of Technical Standards

Lack of technical standards was ranked fifth with a mean score of 3.780. Technical standards include project management standards, big data application standards, transformation process standards, and other standards to measure the success of transformation [3,60,61]. At present, relevant standards and norms were gradually introduced and improved in the Chinese construction industry. For example, China has issued a number of standards and norms on the implementation of BIM, including standards for BIM in construction, standards for design delivery of BIM, etc. [62]. In the meantime, China has also actively participated in the formulation of ISO standards. However, the digital transformation of the construction industry involves many fields, such as BIM, IoTs, cloud computing, AI, blockchain, etc. [20,63], each of which has different technical standards. In addition, due to the complexity and diversity of the construction projects, it is difficult to establish uniform standards [33,64].

4.3. Perceived Impact of Digital Transformation on Project Performance

The questionnaire survey investigated the general perception of project performance improvement by conducting digital transformation. According to PMBOOK, project performance indicators include cost management, schedule management, quality management, integration management, risk management, human resources management, scope management, communications management, and procurement management. Respondents were requested to assess the impact of digital transformation on the nine indicators and overall project performance. Table 7 shows the respondents' perception of project performance improvement.

Digital transformation was perceived to improve the overall project performance by an average increase of 7.2%. Specifically, most respondents considered that there would be a 7–9% increase (36.05% of respondents) followed by a more than 10% increase (27.91% of respondents), 4–6% of increase (26.74% of respondents), and then an increase of 1–3% (9.30% of respondents). In terms of areas, digital transformation affected the procurement management mostly with an average increase of 7.41%, whereas it affected the scope management minimally with an average increase of 6.60%.

The Kruskal–Wallis Test was carried out to test the perception consistency of respondents with different designations, educational experience, and work experience [39]. Table 7 shows that respondents with different backgrounds had the same perception of performance improvement on most of the nine indicators, except for cognitive difference between two areas by the respondents' designation. Table 8 shows the mean score of perceived improvement from respondents with different designations. Government personnel and researchers had a relatively higher perception of performance improvement than experts from the industry in the area of schedule management. Regarding procurement management, researchers, government personnel, and designers thought that digital transformation would bring an increase of 9.05%, 9%, and 8%, respectively, whereas engineers and managers had a relatively lower perception with an increase of 6.55% and 7.31%, respectively.

Table 7. Respondents' perception of project performance improvement.

Areas	0%	1–3%	4–6%	7–9%	≥10%	Mean Value	Rank	*p* Value of Kruskal-Wallis Test		*p* Value of Kolmogorov-Smirnov Test
	Frequency (Percentage)							Designation	Work Experience	Education Experience
Cost management	0(0.00%)	13(15.12%)	21(24.42%)	25(29.07%)	27(31.40%)	6.99%	4	0.134	0.944	0.418
Schedule management	1(1.16%)	7(8.14%)	21(24.42%)	32(37.21%)	25(29.07%)	7.27%	3	0.025 *	0.682	0.203
Quality management	1(1.16%)	11(12.79%)	22(25.58%)	29(33.72%)	23(26.74%)	6.91%	5	0.436	0.320	1.000
Integration management	0(0.00%)	9(10.47%)	20(23.26%)	31(36.05%)	26(30.23%)	7.28%	2	0.112	0.145	0.203
Risk management	0(0.00%)	12(13.95%)	20(23.26%)	35(40.70%)	19(22.09%)	6.91%	5	0.500	0.729	0.182
Human resources management	3(3.49%)	8(9.30%)	23(26.74%)	29(33.72%)	23(26.74%)	6.90%	7	0.173	0.336	0.083
Scope management	1(1.16%)	12(13.95%)	28(32.56%)	23(26.74%)	22(25.58%)	6.60%	9	0.802	0.469	0.996
Communications management	1(1.16%)	12(13.95%)	21(24.42%)	28(32.56%)	24(27.91%)	6.90%	7	0.159	0.525	0.382
Procurement management	0(0.00%)	7(8.14%)	23(26.74%)	26(30.23%)	30(34.88%)	7.41%	1	0.005 *	0.159	0.141
Overall project performance	0(0.00%)	8(9.30%)	23(26.74%)	31(36.05%)	24(27.91%)	7.20%	–	0.144	0.573	0.258

Note: * means that there is significantly perception difference by intergroup comparison.

Table 8. The mean score of perceived improvement from respondents with different designations.

Areas	Researcher	Government Personnel	Engineer	Manager	Designer	Others	*p* Value
Schedule management	8.58%	10.00%	6.65%	6.69%	5.00%	7.88%	0.025
Procurement management	9.05%	9.00%	6.55%	7.31%	8.00%	5.63%	0.005

4.4. Perceived Impact of Digital Transformation on Enterprise Performance

The questionnaire survey investigated the general perception of enterprise performance improvement by conducting digital transformation. According to ESG theory, enterprise performance indicators include environmental performance, social performance, and governance performance. Respondents were requested to assess the impact of digital transformation on the three indicators and the overall enterprise performance. Intergroup comparison was conducted to test respondents' perception consistency. Table 9 shows that the *p* values of the Kruskal–Wallis Test and the Kolmogorov–Smirnov test are greater than 0.05, suggesting that respondents with different designations, work experience, and educational experience had no statistical difference regarding the perception on enterprise performance improvement [43].

Table 9. Perceived enterprise performance improvement.

Areas	0%	1–3%	4–6%	7–9%	≥10%	Mean Value	Rank	*p* Value of Kruskal-Wallis Test		*p* Value of Kolmogorov-Smirnov Test
	Frequency (Percentage)							Designation	Work Experience	Education Experience
Social performance	1(1.16%)	13(15.12%)	21(24.42%)	26(30.23%)	25(29.07%)	6.85%	2	0.298	0.786	0.999
Environment performance	1(1.16%)	18(20.93%)	27(31.4%)	21(24.42%)	19(22.09%)	6.15%	3	0.525	0.977	1.000
Governance performance	1(1.16%)	10(11.63%)	26(30.23%)	24(27.91%)	25(29.07%)	6.88%	1	0.219	0.885	0.480
Overall enterprise performance	0(0%)	13(15.12%)	24(27.91%)	25(29.07%)	24(27.91%)	6.81%	–	0.345	0.979	0.983

All respondents thought digital transformation would improve the overall enterprise performance to some extent. Specifically, most respondents considered that there would be a 7–9% increase (29.07% of respondents), followed by more than a 10% increase (27.91% of respondents) and a 4–6% of increase (27.91% of respondents), and then an increase of 1–3% (15.12% of respondents). In terms of specific indicators, digital transformation affected the governance performance mostly with an average increase of 6.88%, whereas it affected the environment performance minimally with an average increase of 6.15%.

5. Recommendations

Based on the five identified major barriers, this paper carried out five corresponding suggestions. They are implementing data governance system, strengthening technology innovation and introduction, strengthening digital infrastructure, introducing and cultivating digital talents, and establishing technical standards.

5.1. Implementing Data Governance System

Digital transformation needs huge data to support the application of digital technologies [6,65]. However, data standards among governments, industries, and enterprises have not been unified at present, causing data interfaces complications and data sharing issues [2]. Hence, it is necessary to implement a data governance system. As Zorrilla and Yebenes (2022) proposed, a data governance system should meet four specific criteria [66]. First, the principles should be established to guide the governance of data. Second, the criteria for efficient data governance should be carried out, e.g., strategic alignment requirements, organizational requirements, data governance, and administration requirements. Third, the requirements for data management should be established, such as data quality, data security, data privacy, etc. Four, monitoring requirements should be defined to evaluate the performance of data utilization.

5.2. Strengthening Technology Innovation and Introduction

Digital technologies are the footstone for successful digital transformation. There are two ways to pursue the advanced technology, i.e., technology innovation and technology introduction [5]. Technology innovation requires a huge investment of capital and manpower in digital equipment, operation and maintenance platform, data security, and other aspects. Meanwhile, openness, affordances, and generativity are three key themes in technology innovation [67]. The introduction of technology refers to obtaining the external advanced technologies through technology exchange and transfer, and then combining them with the internal characteristics for application [5]. Due to the exclusive characteristics of technology, enterprises should strengthen the ability to digest and absorb technology, and also avoid over-reliance on the introduction of new technology.

5.3. Strengthening Digital Infrastructure

Digital infrastructure is a hardware and software integrated infrastructure driven by data innovation, built mainly by digital materials such as data, software, chips, communication, and molecular coatings [51]. For key infrastructures such as 5G base stations, data centers, and cloud computing centers, the government should deploy them in a planned and step-by-step manner so as to improve communication and connection speed, computing, and storage capabilities, thereby further accelerating the deep integration of digital technology and the construction industry [64]. Meanwhile, the model of investment to digital infrastructure should be innovated. The investment in digital infrastructure projects is huge and its payback period is long, which would impose a financial burden on the government [52]. Hence, private capital can be introduced and cooperate with government funds, strengthening resource integration and increasing the construction speed of digital infrastructure.

5.4. Introducing and Cultivating Digital Talents

There are two main sources of increasing digital talents. One is the introduction of talents with digital ability from outside the enterprise. Another is cultivating internal talents [5]. For the first aspect, enterprises can implement the introduction plan of digital talents and independently introduce digital composite high-end talents. For the second aspect, the enterprise can offer digital transformation training courses and provide various types of learning materials, which will strengthen the existing employees' literacy of digital technology and management [56]. Meanwhile, to reduce brain drain, a systematic and complete digital talent cultivation system and incentive mechanism should be established. The two solutions can help construction enterprises to have sufficient talent for digital transformation.

5.5. Establishing Technical Standards

There are several national standards relevant to digital transformation in China, such as "Integration of information and industrialization—Digital transformation—Reference model for value and effectiveness", "Integration of informatization and industrialization management systems—Guide for digital management of supply chain", "Integration of informatization and industrialization management systems—Operation management specification of production equipment", etc. [68]. These standards effectively encourage firms to reconstruct value systems in the context of digital transformation. Although the underlying logic of digital transformation in the construction industry and other industries is similar compared with manufacturing enterprises, the products of the construction industry have a low degree of standardization and batch replication [5]. Hence, there is a need to design specific technology standards for the digital transformation in the construction industry. Moreover, the technology standards need an overall planning from top to bottom based on the whole industrial chain.

6. Conclusions

This paper has explored the current status, major barriers, and potential impact of digital transformation in the Chinese construction industry. First, 17 potential barriers were identified by the literature review and packaged into three groups: environment related factors, technology related factors, and organization related factors. A large-scale questionnaire survey was then conducted to collect data after a pilot study. The survey result shows that 80% of enterprises where the industry expert works had already formulated digital transformation plans or at least had plans being formulated. In addition, among 14 digital technologies, BIM software was the most commonly used digital technology with 54 votes whereas the mobile technology became the least commonly used technology with 9 votes. By using a mean score ranking, the five most significant barriers were discovered. They were "Data Fragmentation (mean value: 3.930)", "Lack of Core Technology (mean value: 3.870)", "Weak Digital Infrastructure Allocation (mean value: 3.830)", "Lack of Technical Personnel (mean value: 3.800)", and "Lack of Technical Standards (mean value: 3.780)" (which are listed here in order). Moreover, digital transformation was perceived to affect the procurement management mostly at a project level and affect the governance performance mostly at an enterprise level.

While achieving the preset objectives, these findings should be explained in the context of study limitation. First, due to the respondents all being from China, the results may alter in other regions or countries. Second, although the sample size (86 questionnaires) is enough to conduct statistical analysis, it would be better to obtain more samples. Third, these findings are obtained based on the respondents' experience and knowledge, which might be influenced by personal bias.

Despite these limitations, this study has several contributions to make to the field. First, it revealed the current status, major barriers, and potential impact of digital transformation in the Chinese construction industry, which would bridge the knowledge gap in previous studies. Second, this study would provide scholars and practitioners an in-depth understanding of digital transformation in the Chinese construction industry. It might also help policymakers formulate appropriate policies to promote digital transformation. Further research can explore the internal logic of the barriers to digital transformation and identify their hierarchical relationships.

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