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Research on the Influencing Factors of Construction Enterprises' Digital Transformation Based on DEMATEL-TAISM

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Abstract: The ongoing shift from an industrial to a digital economy is a significant global phenomenon. However, the driving forces behind and the tactical approach to digital transformation are still unclear to the construction industry, thereby posing challenges for construction enterprises seeking to undergo digital transformation. Therefore, this paper conducted an investigation on the subject, including the following: (1) the 17 influencing factors in the complex system of digital transformation of construction enterprises were screened and summarized from four perspectives: Environment, Technology, Organisation, and Resources. The attributes of the influencing factors were analyzed using the Decision-Making Experimentation and Evaluation Laboratory (DEMATEL) method, and the key factors were identified. (2) The Total Adversarial Interpretive Structure Model (TAISM) method was used to develop a multi-perspective adversarial recursive structure model with integrated impact values, which reflected the interrelationships between the influencing factors and the hierarchical structure. (3) Based on the analysis of the influencing factors of digital transformation of construction enterprises, the clear path mechanisms were elucidated and suggested measures from the internal and external perspectives of government and construction firms were recommended. The results can offer theoretical backing and serve as a stepping stone for the digital transformation of the construction industry.

Keywords: digital transformation; construction enterprise; DEMATEL-TAISM; influencing factors

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1. Introduction

The global economy has transitioned into a new phase characterized by digitalization, which is facilitated by the widespread adoption of digital technologies. This phenomenon is a crucial aspect of the fourth industrial revolution, and it has led to the digital transformation of businesses worldwide. The adoption of digital transformation by enterprises has become a prevalent trend in numerous countries, with the aim of enhancing competitiveness and achieving sustained growth, such as Germany's "Digital Strategy 2025", China's "Internet +" in 2016, "Smart +" in 2019, "New Infrastructure" in 2020, and "Digital China" in 2023. Numerous nations are progressively enhancing their leadership in digital strategy, prioritizing the digital economy and digital technology as a national approach to facilitate the enhancement of conventional industries and foster their transformation and advancement.

The accompanying changes include not only the application of digital technology [1,2], but also profound changes in business models [3–5]. In contrast to the booming digital economy in other sectors, the construction industry is one of the slowest sectors in the world to develop digitization and automation as per a report released by the McKinsey Global Institute in 2018, concerning China (as depicted in Figure 1) [6].

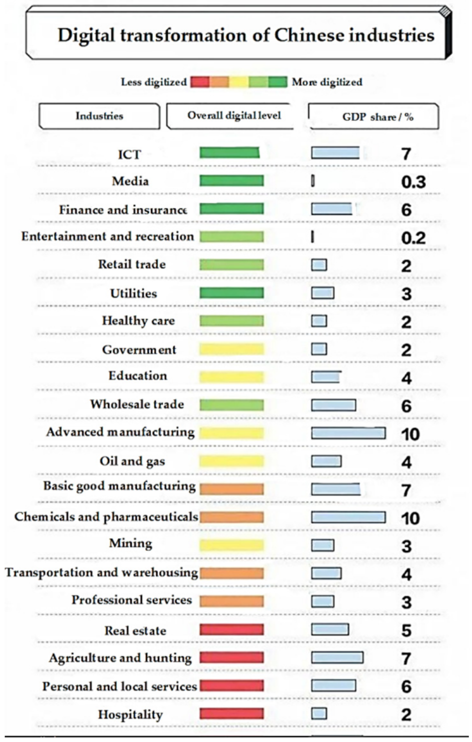

Figure 1. Digital transformation of Chinese industries.

In terms of digitalization, Information and Communication Technology (ICT) was the most digitized, while the construction industry ranks last among 22 industries. The construction industry is known for its fragmented structure, which is marked by interdisciplinary, decentralized, and spontaneous project organization, process discontinuities, and unique projects [7]. This poses significant challenges in meeting the cost, time, and productivity requirements of construction projects, thereby hindering the industry's digital transformation [8].

The construction industry, being a sector that typically requires substantial resources, plays a noteworthy role in the advancement of a country's economy [9]. However, the construction industry's development has been severely hampered by inherent issues such as high consumption, inefficiency, and, in some instances, inadequate administration. In the face of depleting resources, tightening environmental policies, slowing infrastructure investment, and an aging construction workforce, there is an urgent need to accelerate the digital transformation of the construction industry. The implementation of digital transformation has the potential to enhance the data storage and management capabilities of construction organizations, as well as automate and integrate resources throughout the design, construction, and operations phases. This can lead to improved efficiency in material and equipment utilization, as well as the ability to anticipate and mitigate potential safety risks. Ultimately, these benefits can result in reduced costs, increased productivity and efficiency, and improved market competitiveness for construction companies [10,11].

Consequently, promoting the digital transformation of the construction industry has become part of a high-quality, sustainable development strategy, allowing for the inevitable transformation and upgrading of the construction industry [12,13]. In view of the digital transformation of construction enterprises, numerous experts and scholars have investigated the factors that affect this transformation process. Some have directed their attention towards the advancement and implementation of digital technologies. Zhong et al. proposed a new method for real-time compaction quality monitoring with Global Navigation Satellite System (GNSS) and a robotic total station (RTS) based on Positioning Compensation Technology (PCT), a digital method that enables all-terrain, all-course compaction quality monitoring for the earth and rock dam construction [14]. Cheng and Teizer expounded on the implementation of intelligent management technologies that facilitate the real-time acquisition, representation, and interpretation of data pertaining to construction safety and work activity monitoring through the utilization of sensors and positioning technologies [15]. Similarly, Kong and Ma elaborated on three smart construction methodologies that rely on Building Information Modelling (BIM) and Internet of Things (IoT) technologies for monitoring concrete mixing, ensuring tower crane safety, and managing site visualization [16].

While the utilization of digital technology has enhanced the efficacy of construction procedures to some degree and is extensively employed in the construction industry, some scholars argue that the digital transformation of construction firms cannot be exclusively considered from a technological standpoint. Ernstsen et al. highlighted the necessity to focus on the non-technical aspects of digital transformation in construction companies. The mere utilization of technology is insufficient to facilitate the comprehensive digital transformation of an organization. As a result, there is a growing focus on investigating the digital transformation strategy of construction enterprises in research literature [17]. Zhao and Li found through case studies that superficial or one-sided transformation is not only difficult to effectively release the superimposed and multiplying effect of digital technology on enterprise value, but also restricts the operation and development of enterprises and even causes a serious negative impact on performance. This can be particularly problematic for traditional enterprises that are already facing significant pressure to undergo transformation, potentially exacerbating their difficulties [18]. JIA et al. conducted a study and identified several crucial factors that must be given priority and managed effectively to influence the implementation of digital technology in construction management. These factors include cross-disciplinary talent capabilities, conceptual and value perceptions, organizational structure, and IT innovation capabilities [19]. Koscheyev et al. analyzed theoretical approaches to digital transformation in construction enterprises, revealing specific features and problems of certain transformations occurring in construction organizations [20]. Tian et al. examined cases pertaining to the digital transformation of construction firms, synthesized the knowledge and methodologies of digital transformation of them, and posited that construction enterprises can only remain competitive amidst rapid changes by expediting their digital transformation and upgrading from management informatization and construction digitization [21]. Through the analysis of the digital transformation practice of an old construction and engineering company, You et al. found that the case company systematically deploys and implements digital transformation from the top strategy, with the core being the innovation, optimization, reshaping, and transformation of strategy, organization, and processes, and carries out digital construction on the basis of process reengineering and data governance. As a result, the organization achieved commendable outcomes in its transformational efforts. [22].

In addition to exploring the influencing factors from the companies themselves, some scholars have noted that the influence of the external environment has an equally influential role in the digital transformation of construction companies. Kowalkowski et al. in their study of small and medium-sized enterprises (SMEs) argue that meeting market demand is the primary driver of digital transformation for SMEs and that digital transformation to meet market demand is more motivating and sustainable than digital change through a company's own technology, management, and organization [23]. Prebanić et al. highlighted the important role of stakeholder behavior in the digital transformation of construction projects and examined how to influence stakeholder behavior, engagement, and communication styles in projects [24].

The research methods adopted by scholars basically analyze the influencing factors from a qualitative approach for specific cases, while a few scholars include quantitative analysis. Zhu et al. for instance, after distributing questionnaires to scholars of the construction industry and enterprise digitalization, construction enterprise management and research and development (R&D) personnel, identified and extracted the key elements affecting the digital transformation of construction enterprises and used Interpretive Structural

Model (ISM) and Analytic Hierarchy Process (AHP) to calculate the importance of each element [25]. Chen et al. used the practice information of four listed Chinese construction enterprises with different digital development characteristics as data sources and used hierarchical analysis and indicator correlation to construct an evaluation index system for the digital development level of construction enterprises [26].

In summary, it was found that the research on the influencing factors of digital transformation is crucial to the realization of high-quality development of construction enterprises, which has been unanimously recognized by scholars. The predominant research approach utilized to investigate the factors that influence the digital transformation of construction enterprises is qualitative analysis based on specific cases. Despite its ease of operation, this method yields relatively abstract results with limited adaptability. Only a small number of scholars have employed quantitative analysis. For the research content, most of the studies on the digital transformation of construction enterprises stay at the level of what the influencing factors are. In addition, the existing literature on the factors influencing the digital tend to examine these factors in isolation, without employing rigors and systematic research methods to explore their interrelationships. Therefore, there still exist certain deficiencies in comprehending the fundamental constituents that drive digital transformation in the construction sector, the industry as a whole is still in the early stages of exploration. What are the key factors behind digital transformation in the construction industry? What are the structural relationships between these key influencing factors? What mechanisms are needed for digital transformation in the construction industry? Consequently, the digital transformation of construction enterprises remains incomplete and insufficiently comprehensive, posing significant challenges to their multidimensional transformation.

By combining the existing empirical research conclusions and through expert interviews and questionnaires, we established a system of influencing factors for the digital transformation of construction enterprises. Based on the results of the questionnaire survey, the Decision Experimentation and Evaluation Laboratory (DEMATEL) method was used to analyze and determine the self-relevant properties of each influencing factor. The DEMATEL-TAISM method, which integrates the Total Adversarial Interpretive Structure Model (TAISM) method, facilitates the elucidation of interrelationships and hierarchical structure of influencing factors through the creation of an adversarial multi-level recursive structure model. The innovation points of this paper are as follows: (1) For the factors influencing the digital transformation of construction enterprises, 17 representative factors are comprehensively considered and selected, and the role relationship between the factors was studied by DEMATEL, instead of the independent analysis of the influencing factors in the past, to obtain key factors as well as more scientific and reasonable analysis for the digital transformation of construction enterprises. (2) We improved the traditional ISM method to form TAISM and then applied DEMATEL-TAISM to better adapt to the analysis of the complex system of digital transformation of construction enterprises. This approach can offer a holistic framework for complex system hierarchy analysis, yielding an impartial and lucid representation of the structural relationship in system hierarchy from the vantage points of outcome and cause. (3) On the basis of the results of the DEMATEL-TAISM analysis, the path mechanisms of digital transformation were elucidated, thereby providing more comprehensive recommendations and strategies for the implementation of digital transformation from external and internal perspectives.

2. Materials and Methods

2.1. Questionnaire Design

In order to identify the factors influencing the digital transformation of the construction industry, this paper uses literature and on-site research to identify the relevant factors.

Firstly, we searched for the keywords "construction enterprises" and "digitalization" using Web of Science and other search databases to explore the factors influencing the application of digital construction in the construction industry and developed a questionnaire. The questionnaire is shown in Appendix A.

Secondly, based on the whole life cycle theory of construction projects, construction projects can be divided into the decision-making phase, implementation phase, and use phase, which specifically include designable planning, construction, operation, and maintenance. Therefore, we have selected companies that are representative of the various stages of the whole life cycle of a construction project. To enhance the scientific rigor of the study, the selection process prioritized companies that were comprehensive and representative in terms of their nature, size, and other relevant characteristics. We also interviewed experts in universities who are engaged in digital transformation in construction.

Finally, we conducted a questionnaire survey on them, and the structure of the respondents is shown in Figure 2.

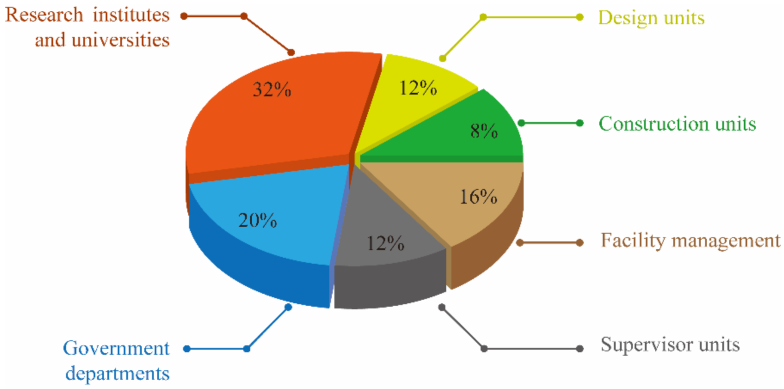

Figure 2. Composition of the investigated respondent's structure.

2.2. DEMATEL-TAISM Combined Model Analysis Method

The Decision Experimentation and Evaluation Laboratory (DEMATEL) method is a widely used method for analyzing uncertain relational factors in systems based on expert cognition [27]. The method is a system factor analysis approach using matrix and graph theory as tools to identify key factors, causal relationships, and other indicators in a complex system by analyzing the logical and direct influence relationships of the elements and quantifying the interdependencies of key factors [28]. It allows for matrix operations on the factors influencing the digital transformation of construction companies in order to determine the causal relationships between indicators and the strength of their impact. The objective is to depict the interrelationships and influences of the model's active elements [29].

The Interpretive Structural Model (ISM) was proposed by Professor Warfield in 1973 and it is widely used in the fields of systems engineering and artificial intelligence. The process of solving the original explanatory structure model uses a result-first hierarchical extraction rule to place each element or influencing factor from top to bottom, and finally obtains a single hierarchical diagram [30]. The intricate interplay of factors that shape the digital transformation of construction enterprises necessitates a comprehensive approach to elucidate the relationships between subsystems in the topological hierarchy. To this end, this study employed the TAISM, which incorporates the concept of game confrontation to derive a more cogent topology that integrates influence values. The TAISM model presents a unique analytical approach in comparison to the conventional ISM. It can be evaluated through two distinct lenses, namely the outcome and the cause, which ultimately culminate in a comprehensive hierarchical structure diagram [31].

The combination of the two methods, DEMATEL and TAISM, increases the amount and accuracy of information between factors, captures the influence and causality of system factors, and is well suited for analyzing problems of influencing factors in complex systems [32]. Two confrontational multi-level recursive structural models of cause and effect can be obtained by this method, allowing for more comprehensive findings and a more convincing hierarchy of factors that can visually represent the degree of influence and hierarchical structure of the relationship between factors. Therefore, the DEMATEL-

TAISM model can be utilized to identify and evaluate the underlying causal components of complex systems and to specify their structural hierarchy.

2.3. Construction of the DEMATEL-TAISM Model

2.3.1. DEMATEL Method

(1) Build the original matrix O

Based on the 17 influencing factors screened out, the inter-influencing relationships between the factors in the multi-dimensional index system were quantified and scored through a questionnaire survey. The main subjects of the survey are construction parties, operation and maintenance management parties, government departments, and university researchers. Scoring the strength of influence between the two factors from 0–4, where 0—no influence, 1—slight influence, 2—general influence, 3—strong influence and 4—very strong. The scoring tables of these experts are collected and aggregated, and the cumulative sum of each quantitative influence relationship in the scoring table is calculated to acquire the multi-factor direct influence matrix O, which is defined as:

$$O = (O_{ij})_{m \times m} \tag{1}$$

where D_{ij} represents the degree of influence of S_i on S_j, m is the number of influencing factors.

(2) Calculate the synthesis influence matrix T

The direct impact matrix O is normalized to obtain the canonical impact matrix N by Equation (2), and then combined with Equation (3) to obtain the integrated impact matrix T. The calculation equations are as follows:

$$N = \left(\frac{O_{ij}}{Max\sqrt{a_i^2 + b_i^2}}\right)_{m \times m} \tag{2}$$

$$\begin{aligned} T = (t_{ij})_{n \times n} &= N + N^2 + N^3 + \cdots N^k \\ &= \sum_{k=1}^{\infty} N^k \rightarrow T = N(I - N)^{-1} \end{aligned} \tag{3}$$

where a_i is the set of sums in each row; b_i is the set of sums in each column; element matrix I denotes the influence of the factor itself.

(3) Identify factors of influence-related indicators

Based on the synthesis influence matrix T, the influence degree (D_i), influenced degree (C_i), centrality degree (M_i), and cause degree (R_i) of each factor are calculated as follows:

$$D_i = \sum_{i=1}^{n} t_{ij} \qquad (i = 1, 2, 3, \cdots, n) \tag{4}$$

$$C_i = \sum_{j=1}^{n} t_{ji} \qquad (i = 1, 2, 3, \cdots, n) \tag{5}$$

$$M_i = D_i + C_i \tag{6}$$

$$R_i = D_i - C_i \tag{7}$$

Centrality degree M_i and cause degree R_i of each factor are respectively taken as horizontal and vertical coordinates in the factor–cause–result diagram, and the position of each constraint is marked in the coordinate axis for intuitive analysis of the importance of each constraint.

2.3.2. TAISM Method

(4) Build the adjacency matrix A

The adjacency matrix describes the direct relationship between each possible pair of factors in the system. According to Equations (8)–(10), the adjacency matrix A is obtained from T. The Equations are as follows:

$$O = (O_{ij})_{m\times m} \tag{8}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n^2} (t_i - \bar{t})^2}{n^2}} \tag{9}$$

$$A_{ij} = \begin{cases} 1 & t_{ij} \geq \lambda \\ 0 & t_{ij} < \lambda \end{cases} \tag{10}$$

where $\bar{t}$ is the mean of the matrix T, and σ is the overall standard deviation.

(5) Build the reachability matrix R

The reachability matrix R is obtained by using "Boolean operations" on the adjacency matrix and the unit matrix, and it describes in matrix form the extent to which the nodes of a directed connected graph can be reached after a certain path length. The Equations are as follows:

$$B = A + I \tag{11}$$

$$B^{k-1} \neq B^k = B^{k+1} = R \tag{12}$$

(6) Build the general skeleton matrix S

In order to simplify the structure of the whole system, the UP-type and DOWN-type hierarchical system is constructed according to the reachable matrix R. The point and edge reduction are carried out to obtain reduction matrix R'. The purpose of the step is to check the relationship between the strong link factors of the reachable matrix, whereas the skip binary relationships between the factors with an adjacent binary relationship are deleted to obtain an edge reduction distance matrix S', and finally, the loop factors are substituted to obtain the general skeleton matrix S. The Equation is as follows:

$$S' = R' - (R' - I)^2 - I \tag{13}$$

(7) Build the matrix with influence values WS

The TS matrix is obtained by substituting the corresponding values in the synthesis influence matrix T matrix into the S matrix at "1" in the matrix S, and then marking the directed edges in the loop as "1" to form the matrix WS with impact values.

(8) Extraction of adversarial hierarchy

Using the reason first and result first extraction methods, the topological hierarchy can be constructed for the purpose of better comprehending the impact of the influencing factors.

According to the reachability matrix K, the reachable set and prior set of each factor can be obtained, which are denoted as $R(S_i)$ and $Q(S_i)$. The reachable set $R(S_i)$ represents the set of elements corresponding to a value of 1 in each row of the reachable matrix K, and the prior set $Q(S_i)$ represents the set of elements corresponding to a value of 1 in each column. And there is a common set $C(S_i)$, where $R(S_i) \cap Q(S_i)$.

For the UP-type hierarchy diagram, the results are prioritized for hierarchical division, and the extraction rules are as follows: $R(S_i) = C(S_i)$. The factor is classified as the first stratum, and then the factor is removed from the reachable matrix K. The above steps are repeated until all factors are completed stratifying the lower stratum indicates that the influencing factor is the root cause, and the upper stratum indicates that the influencing factor is direct. The extraction rule of the DOWN-type hierarchy diagram is $Q(S_i) = C(S_i)$, and the extracted factors are placed below each time from the bottom to the top.

The model framework is shown in Figure 3.

Figure 3. Model framework.

3. Results

3.1. Identifying Factors Influencing Digital Transformation in Construction Enterprises

The authors of this article refer to the classification method in the TOE (Technology–Organization–Environment) theoretical framework approach, analyze and summarise the findings of numerous academic studies on the influencing factors of digital transformation [23–30], while also taking into account the expert interviews of digital transformation of construction enterprises. From both internal and external perspectives, the digital transformation of construction enterprises has been categorized into four distinct areas, namely environment, technology, organization, and resources [25,26,33–35]. A total of 17 factors that exert a significant impact on the digital transformation of construction enterprises have been identified.

(1) The environment is the objective medium basis for the digital transformation of construction companies. It is the external environment faced by construction companies, including the policy environment, competitive pressure, market demand, and the digital standard system. (2) The technology category factor is a measure of the type and stage of digital technology currently used by construction companies, which is closely related to the effectiveness of their own digital transformation. It should include the cost as well as the benefits of technology, in addition to technological renewal changes. (3) The implementation of digital transformation constitutes a significant modification across all facets and operations of a firm, thereby rendering the organizational elements of the construction enterprise pivotal in determining the triumph of the transformation. Organizational factors pertain to the state of the organization, encompassing its strategic plan, structural and cultural framework, and level of synergy within the organization. (4) The concept of digital transformation in construction companies indicates that the transformation process involves the full integration of digital technologies with business management, production, and construction as well as project operations, which leads to a data-driven and innovative

reshaping of strategy, organization and resources in a dynamic external environment of change activities [25]. Resources are therefore also an important consideration for the digital transformation of construction companies, including both on a technical level as well as on other levels, such as talent resources, and knowledge stock.

The specific meaning of each of these indicators, as well as the source literature, are shown in Table 1.

Table 1. Index system of influencing factors.

Terms	Factors	Code	Connotation	Source of Indicators
Environment	Policy environment	S_1	The policy environment provided by the government for the digital transformation of construction companies includes a range of policy measures, such as incentive policies and punishment policies.	[18,25,36–39]
	Competitive pressure	S_2	Construction firms operating in a competitive market environment experience competitive pressures due to the digital transformation initiatives undertaken by their rivals.	[10,21,34,40]
	Market demand	S_3	The degree of digital orientation and demand in the market environment in which construction companies operate.	[20,25,35]
	Digital standards system	S_4	Basic standards related to the application of digital technologies, such as databases, evaluation improvement criteria, and other technical level standards specifications.	[10,22,31,34,36]
Technology	Technical costs	S_5	The costs associated with the digital transformation of construction companies in relation to the procurement, creation, and ongoing maintenance of intelligent systems, machinery, and digital technology.	[14,18,22]
	Digital technology R&D upgrade	S_6	Research and development (R&D) of digital technologies that can be applied in different aspects of construction.	[14,15,34,41,42]
	Economic benefits of digitalization	S_7	Economic benefits gained by construction companies applying digital technologies and digital equipment.	[40,42]
Organization	Organizational strategic plan	S_8	Strategic planning for digital transformation within the construction organization, including the development of digital transformation objectives and planning strategies for construction companies themselves	[25,27,28,39,41,43]
	Organizational structure	S_9	Capable of accommodating the digital organizational framework of construction enterprises, encompassing the partitioning of roles and organizational configurations, including the division of work, responsibilities and authority	[38,41,43,44]
	Organizational synergy	S_{10}	The extent and efficiency of digital business collaboration within the same construction organization and across departments within different business organizations	[25,38,39]
Resources	Talent resources	S_{11}	Construction enterprises with digital-related knowledge.	[4,25,36,38]
	Digital equipment input	S_{12}	The input of intelligent equipment for building planning and design, construction, operation, and management.	[14,15,35,41]
	Digital technology application	S_{13}	Construction companies apply digital technologies such as cloud computing, BIM, and the IoT in all aspects of construction in the process of digitalization.	[14,15,35,41,44]
	Knowledge stock	S_{14}	Knowledge accumulation and knowledge system for digital construction of construction enterprises	[4,25,36,38]
	Data standardization	S_{15}	Standardized extraction, transmission, use, and management of heterogeneous data from multiple	[4,12,15,20,25,36,38,45]
	Integration of software and hardware	S_{16}	The scale and degree of compounding of computer hardware, software, network communication technology, and multimedia application technology in the digital subsystems of construction enterprises	[4,15,25,35,38]
	Diversified digital platforms	S_{17}	Digital platform for technology resource sharing and industry synergy	[4,25,36,38,45]

The above 17 influencing factors can be considered as a complex network, as there are intricate links between the elements. The raw data obtained is shown in Appendix B.

3.2. DEMATEL-TAISM Model Calculation

3.2.1. Results of Applying the DEMATEL Method

We obtained the normative influence matrix by normalizing the direct influence matrix O with Equations (1) and (2). The synthesis influence matrix T was obtained using Equation (3), as shown in Table 2.

Table 2. Synthesis influence matrix T.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	0.003	0.105	0.105	0.032	0.03	0.064	0.099	0.1	0.029	0.044	0.027	0.125	0.124	0.021	0.025	0.024	0.034
S_2	0.004	0.008	0.009	0.007	0.021	0.108	0.033	0.067	0.019	0.069	0.023	0.124	0.123	0.014	0.017	0.022	0.069
S_3	0.014	0.104	0.005	0.009	0.02	0.1	0.034	0.065	0.027	0.033	0.015	0.045	0.045	0.01	0.01	0.018	0.027
S_4	0.011	0.019	0.013	0.004	0.017	0.1	0.028	0.014	0.011	0.04	0.02	0.127	0.129	0.013	0.106	0.111	0.121
S_5	0.004	0.023	0.014	0.009	0.013	0.105	0.112	0.051	0.014	0.032	0.031	0.126	0.128	0.013	0.009	0.024	0.035
S_6	0.004	0.019	0.012	0.006	0.094	0.023	0.109	0.014	0.012	0.028	0.029	0.128	0.128	0.024	0.023	0.068	0.075
S_7	0.004	0.102	0.029	0.005	0.013	0.034	0.021	0.027	0.013	0.0604	0.013	0.111	0.11	0.012	0.014	0.019	0.028
S_8	0.004	0.015	0.009	0.007	0.016	0.101	0.04	0.008	0.101	0.108	0.025	0.111	0.109	0.015	0.008	0.016	0.021
S_9	0.003	0.014	0.008	0.008	0.005	0.017	0.098	0.019	0.007	0.105	0.028	0.026	0.029	0.011	0.005	0.012	0.015
S_{10}	0.003	0.024	0.008	0.004	0.007	0.038	0.065	0.021	0.036	0.017	0.017	0.035	0.027	0.005	0.005	0.008	0.077
S_{11}	0.004	0.009	0.006	0.009	0.014	0.101	0.042	0.008	0.011	0.024	0.009	0.113	0.113	0.081	0.009	0.054	0.092
S_{12}	0.003	0.007	0.005	0.005	0.007	0.016	0.011	0.009	0.009	0.026	0.004	0.009	0.017	0.012	0.012	0.01	0.012
S_{13}	0.003	0.007	0.004	0.005	0.011	0.019	0.036	0.006	0.005	0.033	0.026	0.033	0.014	0.013	0.007	0.013	0.016
S_{14}	0.003	0.01	0.008	0.006	0.013	0.066	0.049	0.018	0.011	0.017	0.009	0.11	0.109	0.005	0.007	0.013	0.042
S_{15}	0.003	0.006	0.004	0.004	0.01	0.019	0.017	0.013	0.006	0.016	0.008	0.036	0.052	0.01	0.004	0.092	0.097
S_{16}	0.003	0.008	0.005	0.006	0.007	0.025	0.029	0.012	0.012	0.058	0.021	0.089	0.101	0.015	0.017	0.008	0.101
S_{17}	0.005	0.011	0.007	0.006	0.011	0.025	0.038	0.016	0.012	0.056	0.021	0.101	0.104	0.015	0.012	0.015	0.01

Based on Equations (4)–(7), the influence degree (D_i), influenced degree (C_i), centrality degree (M_i), and cause degree (R_i) were calculated for each constraint, as shown in Table 3. OF denotes the outcome factor, CF denotes the cause factor.

Table 3. The results of each impact factor calculation.

Factors	D_i	C_i	M_i	R_i	*Attributes*
Policy environment	0.969	0.079	1.048	0.891	CF
Competitive pressure	0.653	0.487	1.14	0.166	CF
Market demand	0.534	0.252	0.786	0.283	CF
Digital standards system	0.882	0.131	1.013	0.752	CF
Technical costs	0.734	0.308	1.042	0.426	CF
Digital technology R&D upgrade	0.788	0.946	1.734	−0.157	OF
Economic benefits of digitalization	0.577	0.877	1.454	−0.301	OF
Organizational strategic plan	0.716	0.402	1.118	0.313	CF
Organizational structure	0.41	0.319	0.728	0.091	CF
Organizational synergy	0.425	0.697	1.122	−0.272	OF
Talent resources	0.626	0.32	0.946	0.306	CF
Digital equipment input	0.174	1.44	1.614	−1.266	OF
Digital technology applications	0.249	1.454	1.703	−1.205	OF
Knowledge stock	0.492	0.217	0.709	0.275	CF
Data standardization	0.395	0.289	0.684	0.107	CF
Integration of software and hardware	0.518	0.525	1.044	−0.007	OF
Diversified digital platforms	0.464	0.864	1.328	−0.4	OF

In order to analyze the attributes and characteristics of each factor more clearly and visually, a diagram was drawn as shown in Figure 4.

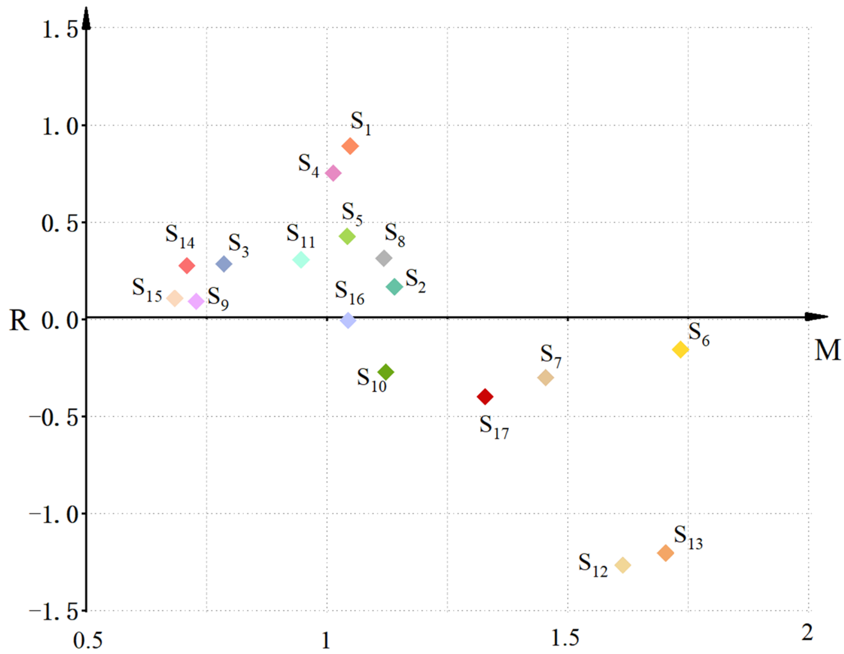

Figure 4. Scatter diagram of centrality and causality.

3.2.2. Results of Applying TAISM Calculations

The commonality between DEMATEL and TAISM dictates that the reachable matrix can be obtained from the synthesis influence matrix T. Firstly, it is necessary to establish an appropriate threshold λ in order to simplify the structure of the system part. The optimal value of λ was calculated to be 0.07 according to Equations (8) and (9) and the reachability matrix R was obtained by Equations (10)–(12), as shown in Table 4.

Table 4. The reachability matrix *R*.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	1	1	1	0	1	1	1	1	1	1	0	1	1	0	0	0	1
S_2	0	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0	1
S_3	0	1	1	0	1	1	1	0	0	0	0	1	1	0	0	0	1
S_4	0	1	0	1	1	1	1	0	0	0	0	1	1	0	1	1	1
S_5	0	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0	1
S_6	0	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0	1
S_7	0	1	0	0	1	1	1	0	0	0	0	1	1	0	0	0	1
S_8	0	1	0	0	1	1	1	1	1	1	0	1	1	0	0	0	1
S_9	0	1	0	0	1	1	1	0	1	1	0	1	1	0	0	0	1
S_{10}	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1
S_{11}	0	1	0	0	1	1	1	0	0	0	1	1	1	1	0	0	1
S_{12}	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
S_{13}	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
S_{14}	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0
S_{15}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1
S_{16}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	1
S_{17}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1

The reduction point is carried out by the reachable matrix R. According to step (6) and Equation (13), the general skeleton matrix S after structural optimization can be calculated as shown in Table 5.

Table 5. General skeleton matrix *S*.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0
S_2	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	1
S_3	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
S_4	0	1	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0
S_5	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
S_6	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1
S_7	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	1
S_8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
S_9	0	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0
S_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S_{11}	0	1	0	0	1	1	1	0	0	0	0	0	0	1	0	0	1
S_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{14}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
S_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
S_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
S_{17}	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0

The 1 value in the general skeleton matrix *S* was replaced with the synthesis influence value, and *WS* is the matrix with influence values that can be obtained by step (7), as shown in Table 6.

Table 6. The matrix with influence values *WS*.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	0	0.105	0.105	0	0	0	0.099	0.1	0	0	0	0.125	0.124	0	0	0	0
S_2	0	0	0	0	1	1	1	0	0	0	0	0.124	0.123	0	0	0	0
S_3	0	0.104	0	0	0	0.1	0	0	0	0	0	0	0	0	0	0	0
S_4	0	0	0	0	0	0.1	0	0	0	0	0	0.127	0.129	0	0.106	0.111	0.121
S_5	0	1	0	0	0	1	1	0	0	0	0	0.126	0.128	0	0	0	0
S_6	0	1	0	0	1	0	1	0	0	0	0	0.128	0.128	0	0	0	0.095
S_7	0	1	0	0	1	1	0	0	0	0	0	0.111	0.11	0	0	0	0
S_8	0	0	0	0	0	0.101	0	0	0.101	0.108	0	0.111	0.109	0	0	0	0
S_9	0	0	0	0	0	0	0.098	0	0	0.108	0	0	0	0	0	0	0
S_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.077
S_{11}	0	0	0	0	0	0.101	0	0	0	0	0	0.113	0.113	0.11	0	0	0.092
S_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S_{14}	0	0	0	0	0	0	0	0	0	0	0	0.098	0.109	0	0	0	0
S_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.092	0.097
S_{16}	0	0	0	0	0	0	0	0	0	0	0	0.089	0.101	0	0	0	0.101
S_{17}	0	0	0	0	0	0	0	0	0	0	0	0.101	0.104	0	0	0	0

According to the stratum extraction method in step (8) in the previous section, adversarial level extraction results were obtained as shown in Table 7.

Table 7. Adversarial level extraction results.

Level	Result Priority-Up Type	Reason Priority-Down Type
Level 1	S_{12}, S_{13}	S_{12}, S_{13}
Level 2	S_{14}, S_{17}	S_{17}
Level 3	S_2, S_5, S_6, S_7, S_{10}, S_{16}	S_2, S_5, S_6, S_7, S_{10}
Level 4	S_3, S_9, S_{11}, S_{15}	S_9, S_{16}
Level 5	S_4, S_8	S_3, S_8, S_{14}, S_{15}
Level 6	S_1	S_1, S_4, S_{11}

Based on the correlation and extraction results between factors, a schematic diagram of the directed topology hierarchy can be drawn. There was a reachable relationship among factors in the system, and the banded line segments were used to represent the accessibility of the influencing factors. The UP-type and DOWN-type topological hierarchical structural model diagrams are depicted in Figures 5 and 6, respectively.

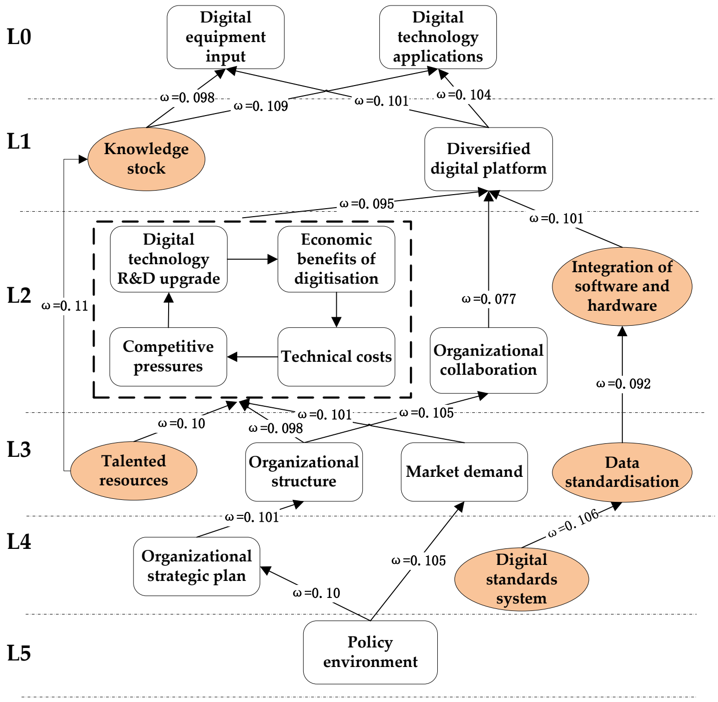

Figure 5. UP-type topological hierarchical structural model diagram.

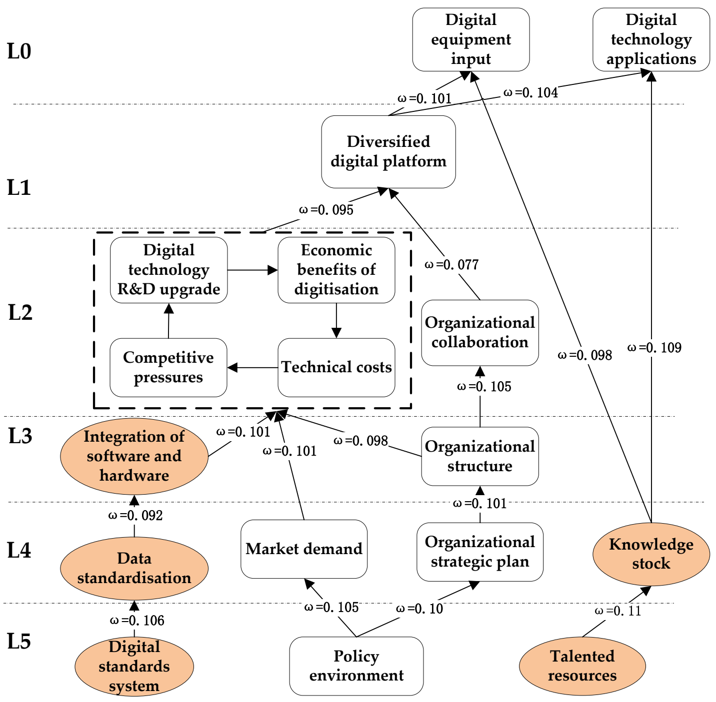

Figure 6. DOWN-type topological hierarchical structural model diagram.

4. Discussion

4.1. DEMATEL Analysis Results

The reason degree is a measure of the influence of a factor on other factors, that is, when $R_i > 0$, the factor is the CF (Cause Factor), the higher the value of R_i, the more it is influenced by other factors. When $R_i < 0$, the factor is the OF (Outcome Factor), and the smaller the value of R_i, the more it is influenced by other factors. The centrality is a function of the influence of the measured factor on the whole system. The larger the value of the factor, the more important the factor is, and the stronger its influence in the system.

According to Figure 5, we can see that the top five factors in terms of centrality factors among the factors influencing the digital transformation of construction enterprises are digital technology R&D upgrade S_6, digital technology applications S_{13}, digital equipment input S_{12}, economic benefits of digitalization S_7, and diversified digital platforms S_{17}. The above factors play an important role in the digital transformation process of construction enterprises. And the top five factors in terms of cause degree are policy environment S_1, digital standards system S_4, technical cost S_5, organizational strategic plan S_8, and talent resources S_{11}, which play significant roles in influencing the other factors. Comparison of the findings with those of other studies confirms that they are important factors, on the basis of which this study obtained the degree of influence and the degree of being influenced by the factors, and determined the attribute characteristics of each factor.

It is worth noting that the analysis results show that the top five influencing factors in terms of centrality are all outcome influencing factors, which indicates that although the above five factors are important in the digital transformation of construction enterprises, they are vulnerable to the strong influence of other factors. It indicates that in order to achieve the digital transformation of construction enterprises, it is necessary to dig into the deep causes and focus on strengthening the control of the causal factors.

4.2. TAISM Analysis Results

(1) The entire system is an active, topologically mutable system.

A topological active system is a collection of mutually antagonistic topological hierarchical diagrams in which the active factors exist at various levels. If, on the other hand, all factors must exist at the same level, this is a rigid requirement, and the resulting topological system is rigid. The orange-marked factors in the system are activity factors of Figures 5 and 6, such as the knowledge stock S_{14}, which jumps between L_2 and L_5, so the study of key factors and driving paths for the digital transformation of construction enterprises is a topological activity system.

(2) Loop analysis.

A causal relationship is represented by a straight line in an adversarial hierarchy diagram. Two-way connections, also called loops or high connectedness, indicate the existence of a relationship between the two components. In Figures 5 and 6, we can see that there is a loop consisting of four factors, namely competitive pressure S_2, digital R&D upgrade S_6, technology cost S_5, and digital economic benefit S_7, which are causally related to each other and have strong connections, and so the loop can be considered as a subsystem of the system.

(3) Hierarchical analysis.

Figures 5 and 6 show that the system of factors affecting the digital transformation of construction enterprises forms a set of six layers of topology, with directed line segments being the cause elements pointing to the result factors, and the two full series of cause and effect do not exactly coincide, which is characteristic of the activity system. The system can be divided into three levels: the substantive layer (L_5), the transitional layer (L_2–L_4), and the surface level (L_0–L_1).

Substantive layer (L_5): The policy environment S_1 is the fixed deep layer factor in the system and has a fundamental impact on the digital transformation of the construction industry (the substance layer), emitting only directed line segments that can influence the factors in the other layers. This also accords with our earlier observations, which showed that policy support of the enterprise was the most profound underlying influence in Zhu and Yan's study [25]. This factor can have an impact on the intensity of market demand and the strategic planning of the digital transformation of construction enterprises, which in turn affects the organizational structure of construction enterprises, the development of digital technologies, and other relevant factors. In order to facilitate the digital transformation of the construction industry, the root cause role of the government, therefore, needs to be given sufficient attention.

Surface level (L_0–L_1): The surface-level factors that have the most direct impact on the digital transformation stage of construction enterprises are the digital equipment input S_{12}, digital technology applications S_{13}, and diverse digital platforms S_{17}. The digital transformation of construction companies can be quickly and effectively regulated by surface-level factors. However, surface-level factors are susceptible to other factors, so when controlling surface-level factors, attention is also paid to the control of their antecedent factors.

Transitional layer (L_2–L_4): The set of transitional layer factors, which includes competitive pressure S_2, market demand S_3, digital standards system S_4, technical costs S_5, digital technology R&D upgrade S_6, economic benefits of digitalization S_7, organizational strategic plan S_8, organizational structure S_9, organizational synergy S_{10}, talent resources S_{11}, knowledge stock S_{14}, data standardization S_{15}, integration of software and hardware S_{16}. These influence upper-level factors by sending upward arrows, and digital platform construction relies on factors such as digital technology R&D upgrade $S_{6,}$ organizational synergy S_{10}, which are also influenced by deeper factors, including talents resources S_{11}, organizational structure S_9, and integration of software and hardware S_{16}. Transitional level factors in a system take on both the role of spreading (transitional) influences, but can also be a source of influence itself, affecting other factors.

Compared to the traditional ISM approach in other studies, the TAISM, which introduces the idea of adversarial games, allows both cause-based and outcome-based recursive structural models to be obtained in this study, providing a better model basis for addressing the digital transformation of construction companies.

Based on the calculations and analysis of the results, the government and construction enterprises should form a digital transformation internal and external synergy mechanism. The government can play a fundamental guiding and restraining role outside, and form a synergy with the internal dynamics of construction enterprises themselves to jointly promote the digital transformation process of construction enterprises. This paper can propose targeted countermeasures and recommendations for the digital transformation of construction enterprises, the framework diagram is shown in Figure 7.

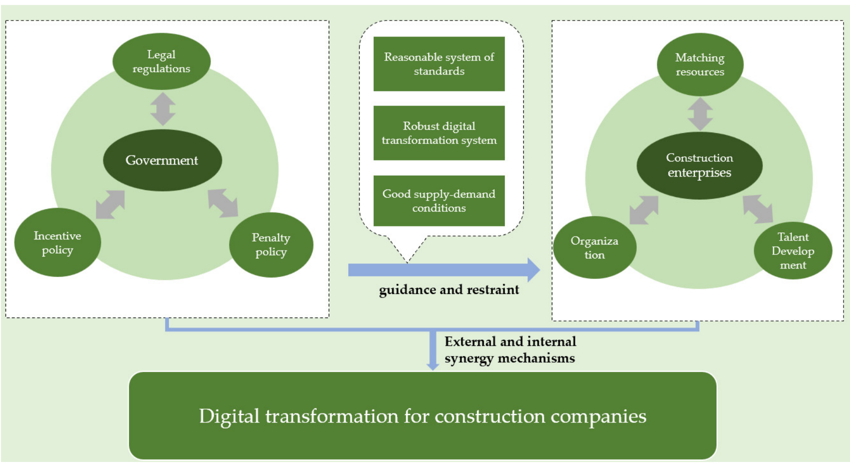

Figure 7. Construction enterprise digital transformation framework.

5. Conclusions and Suggestions

The digital economy has reached a new phase of development, which has led to a corresponding transformation and development in the construction industry. The conventional development model is no longer sufficient to meet the industry's requirements for high-quality and sustainable development. In response to the rapid growth of a new generation of information technology and the need for deep integration with the real economy, construction enterprises are entering a new phase of digital transformation. Currently, the digital infrastructure supporting the transformation of construction enterprises is deficient, and the strategic roadmap for such transformation remains ambiguous. This study presented a comprehensive framework for establishing an index system of factors that influence the digital transformation of construction enterprises and employed an enhanced approach, namely DEMTATEL-TAISM, to conduct an analytical identification of the principal factors and their inter-factor associations. In contrast to the conventional ISM framework, this approach yielded a hierarchical representation of reverse extraction through diagrammatical means, as well as added the influence coefficient values in the comprehensive system model that enhances its ability to visually depict the interrelationships among elements, thereby bolstering its overall persuasiveness. It can further measure the influence path and hierarchical distribution in the system of digital transformation for construction enterprises. Finally, a multi-level recursive structure model with three levels was obtained, that is, the substantial level, the transitional level, and the surface level.

The fundamental catalyst for digital transformation in the construction industry is a favorable policy environment. The direct factors contributing to this transformation include the digital equipment input S_{12}, digital technology applications S_{13}, and diverse digital platforms S_{17}. and between the fundamental and direct factors, factors such as digital technology R&D upgrade S_6 and digital technology applications S_{13}, are influenced by the lower factors and transmitted upwards to form the transitional layer. According to the results of the study, the policy environment provided by the government and the corresponding laws and regulations can be regarded as deep and external guidance, which can provide a suitable environment for the digital transformation of construction enterprises such as system construction and market demand. The internal mechanisms of construction enterprises, including digital organization, resource investment, talent training, and digital management, provide an internal impetus for the digital transformation of construction enterprises. The corresponding countermeasures are proposed from the perspectives of both the government and construction enterprises to form a synergy from outside and inside to jointly promote the digital transformation of construction enterprises.

As a result, the promotion of digital transformation in construction enterprises can be initiated by focusing on the subsequent aspects.

(1) Exert the government's capacity to provide guidance in the digital transformation process of construction enterprises.

As a traditional industry, construction has been unable to establish a wholly market-driven development pattern and is heavily influenced by government policies. According to the findings of this study, the policy environment has a substantial impact on the digital transformation of construction companies, and the digital standards system also has a fundamental impact on the cause type. Therefore, the government assumes a crucial role in facilitating the advancement of digital development.

On the one hand, in the policy landscape, construction enterprises are subject to both incentive and punitive policies. The policy framework plays a crucial role in stimulating favorable market demand for the digitization of construction enterprises. A positive policy environment can stimulate the demand for digitalization in the market and increase the enthusiasm of construction enterprises for digital transformation across the board. More specifically, given the complex network of stakeholders involved in the construction industry, the government has implemented fiscal policies such as tax breaks, subsidized loans, and financial subsidies. Additionally, there are punitive policies in place for enterprises that are digitally disadvantaged. Improved policies can guide construction companies to proactively develop strategic plans for digital development and facilitate the implementation of digital change and organizational restructuring.

On the other hand, construction enterprises encounter varying degrees of resources, awareness, expertise, and governmental intervention that can serve as a guiding force in the digitalization of different firms. This underscores the importance for construction enterprises to proactively devise strategic plans for digital development, and facilitate the implementation of digital change and restructuring of their organizational structure. The establishment of pertinent data standards and specifications has the potential to facilitate the implementation of data-centric fundamental applications, ultimately enhancing the versatility of digital technologies across all facets of construction enterprises. This, in turn, can serve as a solid technical foundation for the advancement of digital transformation within the construction industry.

(2) Strengthening construction enterprises' own digital application capabilities.

Construction companies themselves can be seen as the internal drivers of digital transformation, and on the basis of the external environment, their own digital capabilities should be enhanced to form a mechanism for internal and external synergy.

(1) Improve the size and quality of the digital workforce in construction companies.

Talent resources comprise a highly significant element that exerts a profound influence on the digital transformation of construction enterprises. Currently, the construction enterprise unit is predominantly staffed by conventional engineering managers and construction personnel, with limited integration and synchronization of emerging digital technologies in practical construction operations. Therefore, enterprises themselves should enhance their digital application capabilities. Specifically, construction enterprises should increase investment in special funds for research on the application of digital technology and for the cultivation of digital talents, and fully exploit educational resources using school-enterprise cooperation. In addition, the retraining of the company's existing employees should be bolstered, and digital technology research and development needs to be vigorously pursued through key projects. This will enable the enterprise staff to acquire and implement digital technologies such as cloud computing, big data, and artificial intelligence, and augment their digital knowledge, thereby improving their proficiency in construction project planning, design, construction, and other stages.

(2) Optimize the digital structure of construction enterprises

The implementation of digital technology and equipment does not inherently enhance the digital management capacity and management efficiency of enterprises, as these factors are outcome-driven. The intermediate factor, is both influenced by deep causes and propagates its own influence, so it is important to consider the adaptability to its deeper layers and the influence on the upper ones. At present, the project management system of most construction enterprises is not sufficiently adapted to digital technology and digital construction processes, so it is necessary to strengthen the top-level planning of the digital transformation of enterprises. It is imperative to enhance the high-level planning of enterprises' digital transformation by formulating digital transformation strategies that are grounded on the business environment and industry-specific features. According to the business environment and the characteristics of the industry, the digital transformation strategy should be devised, to effect a transformation in the digitalization of processes and patterns. Such measures can establish a framework that facilitates the innovation and application of digital technologies and equipment.

(3) Improve the supporting resources for digital transformation

Enhancing the digital infrastructure of enterprises and allocating resources towards their digital transformation in accordance with the external environment, institutional modifications, and technological advancements is of paramount significance. The establishment of unified data standards and application standards, strengthening safety and technical supervision systems, and improving the effectiveness and compatibility of information and data circulation and conversion can provide favorable conditions for software and hardware integration. This, in turn, creates a conducive internal environment for the application of digital technology innovation, enabling the datafication of business processes and enhancing the degree of utilization of the digital platform across various project layers. Examples of such systematization include digital technology business batch measurement, financial computerization, and 3D visualization of the construction environment. Such innovations can help to realize the interpenetration of business management effectiveness, establish a data-driven end-to-end interface between management and technology layers, and improve the enterprise's intensive management capabilities.

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Appendix A

Thank you for taking the time to complete the questionnaire on factors influencing digital transformation in construction companies. This questionnaire can help us to study and analyze the factors influencing the digital transformation of construction enterprises.

1. Basic information

(1). Name of survey subject: ____________________

(2). Type of survey respondents

A. Construction enterprises ( ) B. University or research institute ( )

C. Government departments ( )

If you choose A, continue with questions 3–5, otherwise, start with question 6.

(3) Nature of construction enterprise:

A. State owned tnterprise ( ) B. Private enterprise ()

(4). Size of construction business

A. Large-sized ( ) B. Medium-sized ( ) C. Small-sized ( )

(5). Main business

A. Design planning ( ) B. Construction ( ) C Supervisors D. Operations management ( )

(6). Whether working with digital transformation

A. Yes ( ) B. No ( )

The factors influencing the digital transformation of construction companies are given below, and the influencing factors are defined as Si, as shown in Table A1 below:

Table A1. Index system of influencing factors.

Terms	Factors	Code	Connotation
Environment	Policy environment	S_1	The policy environment provided by the government for the digital transformation of construction companies includes a range of policy measures, including incentive policies as well as disincentive policies.
	Competitive pressure	S_2	Construction firms operating in a competitive market environment experience competitive pressures due to the digital transformation initiatives undertaken by their rivals.
	Market demand	S_3	The degree of digital orientation and demand in the market environment in which construction companies operate.
	Digital standards system	S_4	Basic standards related to the application of digital technologies, such as databases, evaluation improvement criteria, and other technical level standards specifications.
Technology	Technical costs	S_5	The costs associated with the digital transformation of construction companies in relation to the procurement, creation, and ongoing maintenance of intelligent systems, machinery, and digital technology.
	Digital technology R&D upgrade	S_6	Development and upgrading of digital technologies that can be applied in different aspects of construction.
	Economic benefits of digitalization	S_7	Economic benefits gained by construction companies applying digital technologies and digital equipment.
Organization	Organizational strategic plan	S_8	Strategic planning for digital transformation within the construction organization, Including the development of digital transformation objectives and planning strategies for construction companies
	Organizational structure	S_9	Capable of accommodating the digital organizational framework of construction enterprises, encompassing the partitioning of roles and organizational configurations, including the division of work, responsibilities, and authority
	Organizational synergy	S_{10}	The extent and efficiency of digital business collaboration within the same construction organization and across departments within different business organizations
Resources	Talent resources	S_{11}	Construction enterprises with digital-related knowledge.
	Digital equipment input	S_{12}	The input of intelligent equipment for building planning and design, construction, operation, and management
	Digital technology applications	S_{13}	The application of technology Construction companies apply digital technologies such as cloud computing, BIM, and the IoT in all aspects of construction in the process of digitalization.
	Knowledge stock	S_{14}	Knowledge accumulation and knowledge system for digital construction of construction enterprises
	Data standardization	S_{15}	Standardized extraction, transformation, transmission, use, and management of heterogeneous data from multiple
	Integration of software and hardware	S_{16}	The scale and degree of compounding of computer hardware, software, network communication technology, multimedia application technology, etc. in the digital subsystems of construction enterprises
	Diversified digital platforms	S_{17}	Digital platform for technology resource sharing and industry synergy

Instructions for completing: Please score the factors in Table A2 using the following scoring rule: the degree of influence of each factor in the column on each factor in the row is scored on a scale of 0–4, where 0—no influence, 1—slight influence, 2—general influence, 3—strong influence and 4—very strong influence.

Table A2. Digital transformation influencing factors for construction enterprise scorecard.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1																	
S_2																	
S_3																	
S_4																	
S_5																	
S_6																	
S_7																	
S_8																	
S_9																	
S_{10}																	
S_{11}																	
S_{12}																	
S_{13}																	
S_{14}																	
S_{15}																	
S_{16}																	
S_{17}																	

Appendix B

The summary results of the questionnaire data are shown in Table A3.

Table A3. Results of data collection.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
S_1	0	38	46	13	9	11	35	36	6	4	7	35	35	6	7	4	4
S_2	1	0	2	2	4	40	3	42	2	22	6	40	40	3	5	4	27
S_3	6	45	0	3	4	35	6	33	7	5	3	3	3	2	2	3	4
S_4	4	5	4	0	2	39	1	2	2	8	4	40	40	2	46	42	42
S_5	1	4	4	3	0	40	42	20	2	3	10	41	42	3	1	5	8
S_6	1	2	3	1	41	0	40	1	3	1	9	40	40	8	8	27	26
S_7	1	44	12	1	3	5	0	5	2	40	2	39	39	3	4	5	6
S_8	1	3	2	2	2	40	3	0	44	40	7	39	39	4	1	2	3
S_9	1	1	2	3	1	2	39	6	0	42	11	2	4	4	1	3	3
S_{10}	1	6	2	1	1	13	39	7	15	0	6	7	3	1	1	1	1
S_{11}	1	1	1	3	1	42	10	1	3	3	0	38	38	2	1	20	35
S_{12}	1	2	2	2	2	5	2	3	3	10	1	0	4	5	5	3	3
S_{13}	1	1	1	2	4	5	13	1	1	12	11	9	0	5	2	4	4
S_{14}	1	1	2	2	2	26	16	6	3	1	1	41	41	0	1	2	15
S_{15}	1	1	1	1	3	5	3	4	1	1	1	6	13	3	0	41	39
S_{16}	1	1	1	2	1	6	6	3	3	20	7	31	37	5	6	0	43
S_{17}	2	2	2	2	3	6	11	5	3	20	7	39	41	5	4	4	0

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