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Research on Influencing Factors of Digital Transformation of Construction Enterprises Based on SEM and fsQCA Methods

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Abstract

This study combines Structural Equation Modeling (SEM) and Fuzzy-Set Qualitative Comparative Analysis (fsQCA) methods to systematically analyze the key factors affecting the digital transformation of construction enterprises, and to propose differentiated implementation paths and strategies based on these factors. The results of the fsQCA analysis show that the four combination configurations affecting the effectiveness/success of digital transformation of construction enterprises from a group perspective are identified as/can be categorized as "technology-organization dual-driven" and "environment-capability leverage". The study proposes countermeasures based on the results of the model and the current challenges, in order to offer insights for/serve as a reference for the successful implementation of digital transformation in construction enterprises.

Keywords: construction enterprises; digital transformation; influencing factors; SEM; fsQCA

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1. Introduction

As a traditional resource-intensive industry, the construction industry has made significant contributions to the national economic development. However, the persistent structural contradictions in this sector, including high resource consumption intensity, low production efficiency, and an ineffective management mechanism [1], have significantly hindered the industry's sustainable development process. Against this backdrop, the implementation of digital transformation serves not only as an essential avenue/a crucial approach to overcome the development bottlenecks faced by industries but also as an integral component within the national industrial upgrading strategic framework [2]. According to the "Statistical Analysis of the Development of the Construction Industry in 2024" released by the China Construction Industry Association in March 2025 [3], the cumulative total industry output value of qualified general contracting and specialized contracting enterprises (excluding labor subcontracting enterprises) across the country in 2024 amounted to CNY 32.65 trillion yuan, with a year-on-year growth rate of 3.8%. Compared to the industry development trend in 2023, the growth rate of output value in 2024 shows a marked deceleration. Additionally, the overall indicator for housing construction continues to decline, suggesting that the industry has entered a phase of profound structural adjustment. The multi-agent collaborative characteristics and complex industrial chain structure unique to the construction industry have led to prominent issues such as inconsistent data collection standards and fragmented information exchange channels throughout the process. The specific manifestations include heterogeneous data formats across departments, redundant multi-party collaboration processes, and repetitive statistical verification stages, which substantially impair the overall operational efficiency. With the popularization of new-generation information technology, digitalization is regarded as the key path to break through industry predicaments and enhance core competitiveness [4]. Digital transformation effectively breaks down information barriers in traditional business scenarios by building real-time data collection systems, establishing cloud-based collaborative platforms, and deploying intelligent algorithm applications. By leveraging the full chain of data connectivity and intelligent analysis technologies, it realizes the dynamic optimization of decision support systems, fully unleashes the value of data assets, and thereby improves the management efficiency throughout the project cycle [5].

Reflecting on the evolution of digitalization in the construction industry, each technological advancement has introduced both novel opportunities and transformative challenges to the industrial ecosystem. Presently, a new generation of digital technology systems—centered around cloud platforms, Internet of Things (IoT) sensing, mobile interconnection, and artificial intelligence—is propelling construction enterprises to reengineer their production processes and management frameworks, signifying the industry's formal transition into an era of intelligent management [6]. While leading enterprises have gained significant benefits through digitalization and established exemplary models, when compared with the manufacturing and financial sectors—pioneers in digital transformation—the construction industry still encounters development bottlenecks, including inadequate depth of technology application and limited system integration [7]. In China, the lagging digitalization process of the construction industry has substantially affected the implementation efficiency of the national "dual carbon" goal-driven industrial upgrading strategy. Against this backdrop, construction enterprises, as the main players in the construction industry, need to undergo systematic reforms to build core competitiveness, foster a digital ecosystem, and achieve high-quality development.

2. Literature Review

2.1. Digital Transformation

In the digital age, the digital transformation of the construction industry is a pressing issue. Compared to other industries, the construction sector remains in the early stages of digital transformation [8]. The digital transformation of the construction industry began in the 1990s, with the Chinese government initiating the promotion and application of CAD technology as early as 1991 [9], thereby driving the digital transformation of the construction sector. Three years later, Oloufa et al. [10] applied GIS to soil analysis for building foundation drilling. Since then, the digital transformation of the construction industry, particularly Building Information Modeling (BIM), has gradually become a consensus within the industry [11].

Since the 21st century, various digital technologies have been applied to multiple aspects of the construction industry [12]. For example, Pin et al. [13] used LiDAR to scan various parts of buildings for precise modeling and subsequent applications. Lin et al. [14] have achieved automatic detection of Personal Protective Equipment (PPE) compliance for construction workers based on intelligent algorithms.

Regarding research on digital transformation, foreign scholars place greater emphasis on exploring its essence and technological implementation pathways, stressing the synergistic evolution of digital technologies and organizational management. Isaev et al. [15] propose that the essence of digital transformation in construction enterprises lies in the dynamic evolution process of achieving deep coupling between digital technologies and organizational business systems, management mechanisms, and business models. Lu [16] focuses on small and medium-sized construction enterprises, revealing that strategic orientation, industry competitive pressures, and policy environments constitute key external variables influencing corporate digitalization. This highlights a research perspective emphasizing the synergistic effects of multidimensional factors. Schönbeck et al. [17] stress that technological implementation must be advanced concurrently with organizational structure optimization, management model innovation, and process reengineering.

However, the digital transformation of the construction industry is not merely about the application of digital technologies [18]. A significant obstacle to achieving digital transformation lies in the institutional environment [19]. To facilitate the digital transformation of the construction industry, construction companies—as the most critical entities in construction activities—must undergo digital transformation [20].

2.2. Digital Transformation of Construction Enterprises

Current research on the factors influencing the digital transformation of construction enterprises has shifted from early single-factor analyses to the development of systematic theoretical frameworks, with research perspectives encompassing multiple dimensions such as technology, organization, and environment, and beginning to focus on the interactions between different factors.

At the technological level, scholars generally agree that the level of digital infrastructure development [2], digital technology application capabilities [4–6], and data integration and analysis capabilities are key factors influencing the transformation process. Some studies have indicated that insufficient technical standardization, poor system compatibility [7], and data silo issues [2] hinder the deep application of digital technologies.

At the organizational level, research primarily focuses on a company's internal strategy, resources, and management capabilities. Senior managers' digital awareness [21] and strategic planning capabilities [22] are considered core drivers of transformation, while organizational structural rigidity [22], shortages of digital talent [2], and insufficient funding [23] constitute major obstacles. Additionally, the extent to which corporate culture accepts change and the cultivation of employees' digital skills [24] are also viewed as important factors influencing transformation outcomes.

At the environmental level, external factors such as policy support [7,25], industry competitive landscape [6,26], and changes in market demand [26] have received widespread attention. Government-issued digitalization support policies have a significant incentive effect on the transformation of construction companies, while inconsistent industry standards and mismatched digitalization levels across the supply chain may delay the transformation process. Some scholars have also explored the influence of macro factors such as the economic environment [27] and the maturity of the technology market [28].

In terms of research methods, early studies primarily employed case analysis and qualitative induction, while recent years have seen the gradual introduction of quantitative methods such as structural equation modeling (SEM) to validate the weights and path relationships of different factors. Studies based on SEM can effectively explore the impact of individual factors on the dependent variable, but they cannot reveal the combined effects of multiple factors on the dependent variable. Since the digital transformation of construction enterprises is typically influenced by these effects, applying a factor interaction perspective (such as fsQCA) to its study can fully explore the differentiated impacts of different factor combinations on transformation outcomes and better reflect the underlying patterns.

2.3. TOE Theory

The TOE theory was proposed by Tornatzky and Fleischer in 1990, building upon the Innovation Diffusion Theory (DOI) and the Technology Acceptance Model (TAM) as its theoretical foundation [29], with the aim of systematically analyzing the complex driving mechanisms behind an organization's adoption of new technologies or innovative behaviors. Its core contribution lies in constructing a three-dimensional analytical framework that integrates technology, organization, and environment, overcoming the limitations of traditional research that relied on single-dimensional explanations [30]. This framework emphasizes the dynamic synergistic effects between external environmental pressures, organizational internal characteristics, and technological attributes [31].

From a theoretical perspective, the technological dimension focuses on the inherent attributes of technology and its interactive relationship with the organization. It encompasses the functional characteristics of technology, the depth of its integration into business scenarios, the long-term benefits of technological investment, and the iterative potential of technological systems [32]. The organizational dimension focuses on internal structural characteristics and dynamic capabilities, such as organizational scale, resource reserves, management's strategic vision, cross-departmental collaboration efficiency, and corporate culture's inclusiveness toward change [33]; he environmental dimension points to macro-level contextual pressures and supportive conditions outside the enterprise, specifically involving industry competition dynamics, government policy orientations, changes in market demand, the level of collaboration across the supply chain, and trends in the evolution of technical standards. These three dimensions do not exist in isolation but interact dynamically to influence organizational decision-making logic. The framework's core characteristics lie in its systematicity, dynamism, and flexibility—it reveals decision-making logic in complex contexts through multidimensional interactions while maintaining broad applicability due to its openness and theoretical compatibility. It does not predefine specific variables, allowing researchers to select appropriate influencing factors based on the research object and combine them with other theories to enhance the analysis [34].

In practice, the TOE framework is particularly suitable for research on organizational change driven by emerging technologies. Its structured dimensional approach not only supports comprehensive analysis of technological feasibility, organizational adaptability, and environmental supportiveness but also enables the identification of differentiated transformation drivers through configuration paths, providing methodological support for exploratory research across industries and firm sizes [35]. In the digital transformation of the construction industry, the TOE framework can systematically integrate technological, organizational, and environmental dimensions to reveal differentiated transformation pathways/logic across enterprises of varying sizes, thereby providing more targeted theoretical and practical guidance for industry practice [36].

3. Research Design

3.1. Research Methods

3.1.1. Structural Equation Modeling (SEM)

SEM is a statistical method that analyzes relationships between variables based on their covariance matrix, serving as a crucial tool in multivariate data analysis. By integrating the Measurement Model and Structural Model, SEM overcomes the limitations of traditional statistical methods, which struggle to simultaneously address measurement error correction and the analysis of multiple mediating effects.

The Measurement Model focuses on the relationship between observed variables and latent variables. By specifying how observed variables measure latent constructs, it simplifies complex real-world phenomena into operable measurable indicators. The validation results of the measurement model (including reliability, validity, and goodness-of-fit tests) serve as the foundation for subsequent structural model analysis. Structural Model reveals causal relationships among latent variables. By quantifying the influence of one or more latent variables on others, it constructs an interconnected network of variable interactions.

Measurement Model Equations:

$$X = \Lambda_x \xi + \delta \tag{1}$$

$$Y = \Lambda_y \eta + \varepsilon \tag{2}$$

Structural Model Equation:

$$\eta = B\eta + \Gamma\xi + \zeta \tag{3}$$

where:

X = vector of observed exogenous variables
Y = vector of observed endogenous variables
Λx = matrix of factor loadings relating X to latent exogenous variables (ξ)
Λy = matrix of factor loadings relating Y to latent endogenous variables (η)
ξ = vector of latent exogenous variables
η = vector of latent endogenous variables
δ = vector of measurement errors for X
ε = vector of measurement errors for Y
B = matrix of path coefficients between endogenous variables
Γ = matrix of path coefficients from exogenous to endogenous variables
ζ = vector of structural residuals

3.1.2. The Applicability of Structural Equation Modeling

The digital transformation of construction enterprises involves multidimensional factors, some of which may be unobservable, with potential direct or indirect interactions between them. SEM effectively addresses these complexities. Furthermore, as the sample data for this study originates from questionnaire surveys, which inherently have subjective characteristics, SEM's ability to tolerate measurement errors provides a crucial advantage. It explicitly models measurement errors in observed variables, thereby enhancing the robustness of parameter estimation. Given these advantages, employing SEM as an analytical framework allows for the effective exploration of the intrinsic relationships among the driving factors in the digital transformation process.

3.1.3. Fuzzy-Set Qualitative Comparative Analysis (fsQCA)

Qualitative Comparative Analysis (QCA) is a hybrid research method bridging case-oriented qualitative approaches and variable-oriented quantitative studies. Rooted in Boolean algebra and set-theoretic logic, QCA enables systematic analysis of small-to-medium sample sizes by identifying configurations of necessary and sufficient conditions that link conditions to outcomes. This method is particularly suited to examining multiple conjunctural causation—the phenomenon where differing combinations of conditions may lead to the same outcome. By analyzing complex interaction patterns among variables, QCA effectively uncovers multiple potential causal pathways.

fsQCA integrates fuzzy-set theory with traditional QCA methods, overcoming the rigid binary limitations of classical set theory. Its core strength lies in its ability to process partial set memberships, allowing conditions to influence outcomes through varying degrees of membership.

Using Boolean minimization algorithms, fsQCA identifies the combinatorial effects of antecedent conditions, revealing substitutional, complementary, or inhibitory relationships among condition variables. This approach moves beyond assuming linear effects of isolated factors. By focusing on "how conditions combine" rather than "which condition matters more," it provides a methodological tool for extracting parsimonious patterns from complex datasets in scientific research.

Unlike traditional statistical methods that assume symmetric causality, fsQCA acknowledges "equifinality" (multiple paths to one outcome) and "causal asymmetry"—where the presence/absence of conditions may asymmetrically influence outcomes. Consequently, this asymmetry better aligns with the nonlinear characteristics of real-world decision-making.

3.1.4. The Applicability of fsQCA to This Study

fsQCA transcends the linear constraints of traditional quantitative research. Conventional statistical methods typically assume independent, additive, and symmetric relationships between independent and dependent variables. Grounded in configurational theory, fsQCA redirects scholarly attention to synergistic effects within causal configurations.

Moreover, fsQCA addresses critical limitations of SEM. While SEM validates linear relationships and effect strengths among latent constructs, it fails to capture complex mechanisms of multi-factor synergy. By mapping causal configurations to outcomes, fsQCA deciphers interdependence among latent variables, elucidating complementarity or substitution effects between core elements.

Crucially, this study operationalizes core latent constructs identified by SEM as fsQCA's antecedent conditions. This integrated approach leverages methodological complementarity: ensuring theoretical rigor while identifying diverse pathways to enhance transformation effectiveness, thereby yielding context-specific implementation pathways for practice.

3.2. Identification of Influencing Factors

A systematic review of authoritative domestic and international databases, including CNKI, VIP Database, Web of Science, and EI, indicates that current research on the driving factors of digital transformation in construction enterprises remains relatively scarce. Existing studies are predominantly focused on the manufacturing sector. In light of this research landscape, this study employs a multi-keyword combination search strategy, utilizing terms such as "digital transformation in the construction industry", "digital transformation", "digital transformation of construction enterprises", "influencing factors", and "obstacle factors." The initial search retrieved 323 relevant documents. Following preliminary screening, irrelevant materials such as reports, briefs, conference abstracts, and interviews were excluded, leaving 69 high-quality documents with strong relevance and academic rigor. Through in-depth analysis of these selected documents, factors with overlapping or similar semantics were consolidated, ultimately identifying 32 factors influencing the digital transformation of construction enterprises.

To better align the influencing factors with the actual circumstances, this paper invited experts to conduct brainstorming sessions to refine and optimize the initial list of influencing factors. Concurrently, experts were invited to distill primary influencing factors based on semantic relevance. Based on the preliminary list of influencing factors, an expert brainstorming framework was designed, and 10 experts were invited to participate in the discussion. Following expert revisions, 5 factors were consolidated; the TOE framework [21] was extended into a 5-dimensional analytical model encompassing "technology, organization, environment, personnel management, and enterprise capabilities". Ultimately forming a list comprising 5 1st factors and 27 2nd factors (see Table 1).

Table 1. Observed Variable Table.

	1st Level Factor	2nd Level Factor	Explanation
Independent variable	Technical factors A	digital technology development maturity A1	The Development Level of Digital Technologies in the Construction Sector
		digital technology application and integration degree A2	The practical application level of digital technologies in the construction industry and their integration with other business processes
		digital infrastructure A3	Information and communication technology systems required for the configuration, monitoring, and operation and maintenance of network equipment and related systems
		digital platform construction A4	Enterprises or governments integrate digital technologies such as cloud computing, big data, artificial intelligence, and the Internet of Things to build a comprehensive technical architecture and operational system with capabilities for data integration, business collaboration, and intelligent decision-making.
		digital synergy degree A5	Refers to the efficiency of data sharing and collaboration across departments and enterprises.
Independent variable	Organizational factors B	digital strategy B1	A systematic, long-term action plan formulated by construction enterprises to address the challenges of digital transformation and seize opportunities presented by digital technology development.
		organizational culture B2	The core values, code of conduct, and cognitive paradigms of an organization, as well as its internal system of institutional norms and regulations.
		organizational structure B3	The fundamental forms of internal division of labor and collaboration within an organization involve a fundamental restructuring of organizational structure, management systems, and value systems.
		management innovation B4	Enterprises are breaking away from traditional management models to establish data-driven decision-making mechanisms and agile organizational processes.
		transformation costs and benefits B5	Initial Investment and Long-Term Benefits of Digital Transformation
		manager support and leadership B6	The level of senior management's commitment to and implementation of digital transformation
Independent variable	Environmental factors C	The completeness of the policy guarantee system C1	The systematic nature and practicality of policies formulated by government departments, including digital technology standards, data security regulations, and fiscal and tax incentives.
		The intensity of policy support and incentives C2	The government encourages and supports traditional construction enterprises to undertake technological upgrades and model innovations through fiscal policies such as loan interest subsidies, tax breaks, and financial subsidies.
		unified technical standards C3	Within the construction industry, authoritative bodies establish and enforce or recommend technical specifications and operational procedures to eliminate technical barriers and reduce collaboration costs.
		industry competition and cooperation C4	The competitive-collaborative relationship among enterprises in the construction industry encompasses both the pursuit of differentiated advantages through technological leadership and ecosystem cooperation involving supply chain digitalization and collaboration.
		market demand C5	Consumer demand for construction products or services in specific market environments
		economic, social and cultural environment C6	Economic growth drives the development of the construction industry, fueling robust demand in the construction market. When corporate profitability is strong, construction companies allocate more capital toward digital transformation. They leverage digital technologies to enhance production efficiency, reduce costs, and boost competitiveness, thereby advancing the digital transformation of both individual firms and the broader construction sector.
		industry digitization level C7	The overall level of digitalization in the construction industry
Independent variable	Personnel management factors D	digital talent reserve D1	The quantity and quality of specialized, multidisciplinary professionals possessing specific digital capabilities within an enterprise or industry.
		employee willingness D2	Employee attitudes and acceptance levels toward digital transformation
		enterprise talent quality D3	Refers to the comprehensive attributes possessed by corporate employees in terms of knowledge reserves, professional skills, overall capabilities, and professional qualities.
		digital project implementation team D4	A dedicated team or department responsible for digital transformation
Independent variable	Enterprise capability factors E	digital dynamic capability E1	The ability of construction enterprises to continuously perceive, acquire, integrate, and adapt to digital technologies and applications during their digital transformation process.
		risk prevention and control capability E2	The ability of construction enterprises to identify, assess, and address various potential risks during their digital transformation process.
		Resource foundations E3	The resources that construction enterprises already possess or can acquire provide the material foundation and driving force for their digital transformation.
		technological innovation and R&D capability E4	Technical capability for enterprises to independently develop or modify digital solutions
		change management capability E5	The systematic capability of construction enterprises to coordinate multiple stakeholders' interests and resolve resistance during digital transformation.
Dependent variable	The observed variables of digital transformation effect F	business efficiency improvement F1	By introducing intelligent systems and automated tools, optimize management processes to reduce human errors and repetitive tasks.
		customer satisfaction F2	With the assistance of digital tools, enterprises can accurately understand and predict customer needs, tailor products or services that meet customer expectations, enhance customer experience and trust, and improve customer satisfaction.
		cost-benefit optimization F3	Production Outcomes and Investment Returns of Digital Transformation in Construction Enterprises
		digital innovation level F4	Reflects the comprehensive capability of construction enterprises to drive the systematic upgrade of their value creation systems through the deep integration of digital technologies with core business elements.

The digital transformation of construction enterprises is a dynamic evolution process involving technological iteration, organizational change, and business model reconstruction.

Its essence is to realize the systematic upgrading of the value creation process through the deep integration of digital technology and construction industry elements. Because the process has the complex characteristics of multi-agent participation, multi-stage evolution, and multi-objective coordination, in order to effectively capture the key changes in the transformation process and reveal its inherent laws, this study sets the effect of digital transformation of construction enterprises as an endogenous latent variable and constructs an observable and quantifiable analysis framework. Based on the research of scholars such as Ko [22], Bernard [23], and Nwankpa [24] on digital transformation, the observation indicators of the digital transformation effect of construction enterprises are set as business efficiency improvement, customer satisfaction, cost-effectiveness optimization, and digital innovation level.

To sum up, the research variables of this paper are 6 factors: technical factors, organizational factors, environmental factors, personnel management factors, enterprise ability factors, and the digital transformation effect of construction enterprises. The observed variables comprise the 31 2nd-level factors listed in Table 1.

Technical factors (A) include digital technology development maturity (A1), digital technology application and integration degree (A2), digital infrastructure (A3), digital platform construction (A4), and digital synergy degree (A5).

Organizational factors (B) include digital strategy (B1), organizational culture (B2), organizational structure (B3), management innovation (B4), transformation costs and benefits (B5), and manager support and leadership (B6).

Environmental factors (C) include the completeness of the policy guarantee system (C1), the intensity of policy support and incentives (C2), unified technical standards (C3), industry competition and cooperation (C4), market demand (C5), economic, social, and cultural environment (C6), and industry digitization level (C7).

Personnel management factors (D) include digital talent reserve (D1), employee willingness (D2), enterprise talent quality (D3), and digital project implementation team (D4).

Enterprise capability factors (E) include digital dynamic capability (E1), risk prevention and control capability (E2), resource foundations (E3), technological innovation and R&D capability (E4), and change management capability (E5).

The observed variables of digital transformation effect (F) are business efficiency improvement (F1), customer satisfaction (F2), cost-benefit optimization (F3), and digital innovation level (F4).

3.3. Research Hypothesis

(1) Technical factors

The key driving factors of the digitalization process of the construction industry include emerging technology systems such as 5G communication, artificial intelligence algorithms, BIM, Internet of Things sensing systems, blockchain distributed ledgers, and big data analysis platforms. By accelerating the transformation of application scenarios, these technology clusters have deeply penetrated into the multi-dimensional fields of the economy and society, and gradually evolved into the basic innovation driving force in the era of the digital economy. With the rapid promotion and application of digital technology, it has not only changed the construction process itself, but also promoted the innovative development of construction enterprises in the direction of service. The research of Yuan et al. [25] shows that digital technology can help construction enterprises tap the value of data and gain new competitive advantages by driving the service innovation of the whole life cycle of the project. Scholars have analyzed the application value of digital technology in core business areas such as financial management and pointed out that the deep integration of business and finance can be realized by building a financial shared service center [26]. Ma et al. [27] combined BIM technology with YOLOv8 to construct a risk early warning model for construction personnel, which effectively reduced the possibility of construction personnel straying into dangerous areas. Craveiroa et al. [28] emphasize the collaborative development of building additive manufacturing and advanced technologies such as the Internet of Things, BIM, and other digital systems, which are reshaping the industrial landscape, improving engineering construction efficiency, and reducing resource consumption. Based on this, the research hypothesis is proposed:

Hypothesis H1. *Technical factors have a positive impact on the digital transformation effect of construction enterprises.*

(2) Organizational factors

Organizational factors are the fundamental factors that need to be overcome in the digital transformation of the construction industry [37]. Organizational culture is the soul of the enterprise. An open and inclusive organizational culture is the catalyst for the digital transformation of construction enterprises. It can stimulate the innovation vitality of employees and make them dare to try new technologies and methods, which is helpful to break the conservative and closed situation of the traditional construction industry. Compared with the traditional hierarchical structure, the flat and networked organizational structure is more suitable for the needs of the digital age, which can improve the efficiency of information transmission and organizational agility, and accelerate the promotion and application of digital technology. Digitization strategy plays a vital role in the digital transformation of enterprises [38]. A systematic and clear digital strategy plays a key role in achieving the goal of resource integration and transformation for construction enterprises. In the process of transformation, if construction enterprises lack clear strategic planning, they are prone to falling into decision-making deviation, resulting in waste of resources, which in turn affects the improvement of their competitiveness [39]. Gurbaxani and other scholars believe that enterprises can gain a competitive advantage through strategic adjustment [40]. Based on this, the research hypothesis is proposed:

Hypothesis H2. *Organizational factors have a positive impact on the effectiveness of digital transformation in construction enterprises.*

(3) Environmental factors

Environmental factors influencing the digital transformation of construction enterprises include policy environment factors and market environment factors. The government has introduced a series of policies to encourage the digital transformation of the construction industry. Through government subsidies and support policies, the cost and risk of construction enterprises adopting digital technologies are reduced, which encourages construction enterprises to actively invest in digital transformation. The growing demand of customers for high-quality construction products and services has become an important driving force for the digital transformation of construction enterprises. With the development of the social economy and the improvement of people's living standards, the demands of customers in the construction industry are undergoing profound changes. This also compels construction enterprises to upgrade and use digital technologies to help them more accurately grasp customer demands and provide more personalized, efficient, and high-quality construction products and services. The volatility and uncertainty of market demand will also make construction enterprises more cautious in making investment decisions for digital transformation, worrying that the return on investment in digital technologies may not meet expectations, thereby affecting their enthusiasm and progress in digital transformation. However, competitive pressure forces enterprises to transform and upgrade to alleviate the resistance brought by market demand fluctuations. Based on this, the research hypothesis is proposed:

Hypothesis H3. *Environmental factors have a positive impact on the effectiveness of digital transformation in construction enterprises.*

(4) Personnel management factors

Digital transformation in construction companies is a change that involves all employees. The digital literacy of employees, the digital talent pool of the organization, and the willingness of employees all have an impact on the digital transformation of construction companies. There is a wide variation in the digital literacy of employees in construction firms. Cetindamar et al. [41] suggest that employees with digital literacy can add to digital transformation projects. Their understanding and application of digital technologies can help them adapt faster to work in digital environments and reduce resistance to digital technology implementation. The digital talent pool is a key support for an organization's digital transformation. Construction companies need to have composite talents who understand both construction and digital technology, and the digital project implementation team constructed by talents with diversified professional backgrounds and collaborative innovation capabilities can significantly enhance the organization's keen insight into market opportunities and precise grasp of the ability through knowledge complementary effects and technology integration advantages [42]. As a labor-intensive industry, frontline workers are the main body of construction activities in the construction industry, and their willingness to embrace digital change seriously affects the effectiveness of digital transformation. Employee resistance can become a key barrier to digital transformation [43]. When frontline employees realize that the enterprise's digital transformation will threaten their own work, they will resist digital change, and resist the change through intentional or unintentional behaviors, which leads to the difficulty of promoting digital transformation smoothly. Based on this, the research hypothesis is proposed:

Hypothesis H4. *Personnel management factors have a positive impact on the effectiveness of digital transformation in construction enterprises.*

(5) Enterprise capability factors

The digital transformation of construction enterprises is not merely a technological upgrade but a systematic project involving strategic reconfiguration, resource reorganization, and organizational change. Enterprise capabilities are the core driving force for construction enterprises to break through the bottleneck of digital transformation and realize the conversion of technological value. Digital dynamic capabilities are the key for enterprises to gain competitive advantages in the digital age. They enable enterprises to flexibly respond to market and technological changes, and achieve continuous innovation and transformation. Research has found that construction enterprises that have achieved success in digital transformation often possess strong digital dynamic capabilities, constantly learning and applying new digital technologies and management concepts to adapt to the development and changes of the industry. A solid resource foundation can ensure the various investments in the digital transformation process of construction enterprises. Construction enterprises with strong dynamic capabilities and resource foundations are more likely to achieve better results in the digital transformation process. During the process of digital transformation, enterprises are confronted with numerous uncertainties and risks. If these risks cannot be effectively identified and controlled, it may lead to the failure of the transformation or the waste of resources. Based on this, the research hypothesis is proposed:

Hypothesis H5. *Enterprise capability factors have a positive impact on the effect of digital transformation in construction enterprises.*

Based on the aforementioned research hypotheses, this study proposes a validation theoretical model, as shown in Figure 1.

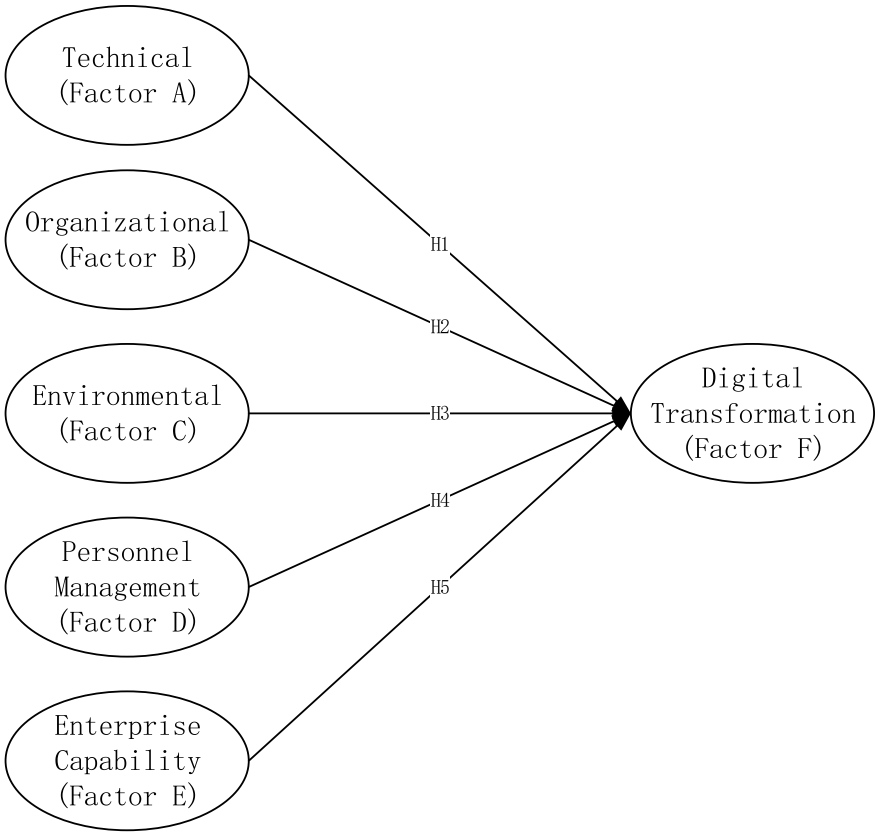

Figure 1. The Theoretical Model.

3.4. Design of the Survey Questionnaire

Based on the latent variables and observed variables proposed in the previous text, and following the practices of predecessors [18], an initial survey questionnaire was designed. Before the formal release, a small-scale pre-research was conducted, distributing it to 60 individuals with relevant professional experience for a small-scale pre-test. According to the feedback from the participants, the items with ambiguous, unclear, or inappropriate expressions were adjusted, modified, and improved. After the revision was completed, it was distributed on a large scale.

The formal questionnaire is mainly divided into two parts. The first part is the investigation of the respondents' personal information, mainly including the years of work experience, job category, type and nature of the affiliated enterprise, and the degree of understanding of digital transformation. The second part is the formal survey questions, including the measurement of each latent variable in this study. A five-point Likert scale is used to score all measurement items. The degree of influence is divided into very little influence, little influence, average influence, considerable influence, and great influence, corresponding to the scores of 1 to 5, respectively.

3.5. Descriptive Statistical Analysis

To facilitate the organization and preservation of the survey content, a questionnaire was created using Wenjuanxing and distributed online to professionals in the construction field and university teachers. A total of 400 questionnaires were collected. After eliminating some questionnaires with unreasonable completion times and those with completely identical answers, a total of 329 valid questionnaires were obtained.

As Table 2 shows, in terms of educational attainment, holders of bachelor's degrees dominate, accounting for 59.3%, while those with master's degrees or higher make up 21.9%, indicating that the respondents as a whole have strong cognitive abilities and can clearly understand and answer the questionnaire questions. Regarding work experience, 44.4% of the respondents have 5 to 10 years of experience, demonstrating a relatively rich accumulation of professional practice. In terms of the distribution of work units, respondents from construction companies account for the highest proportion at 40.4%, followed by design units at 14.6%, and universities and research institutions at 12.2%. The sample group meets the research requirements. In terms of professional titles, respondents with intermediate or higher titles account for a large proportion of the overall sample, at 72%. Notably, 81.2% of the respondents have a clear understanding of the digital transformation of construction enterprises. Overall, the characteristics of the questionnaire sample are of high quality, the data quality is good, and it meets the research design requirements.

Table 2. Descriptive Statistics.

Sample Characteristics	Option	Sample Size	Percentage
Education Background	junior college	62	18.8
	undergraduate course	195	59.3
	Master's degree or above	72	21.9
Work Experience	Less than 5 years	91	27.7
	5 to 10 years	146	44.4
	10 to 15 years	62	18.8
	More than 15 years	30	9.1
Employing Organization	Construction Unit	25	7.6
	Construction Contractor	133	40.4
	Design Unit	48	14.6
	Consulting Unit	21	6.4
	Supervision Unit	21	6.4
	Government Agency	28	8.5
	University or Research Institution	40	12.2
	Other	13	4.0
Enterprise Nature	State-owned	245	74.5
	Privately-owned	57	17.3
	Other	27	8.2
Professional Title	Professor	10	3.0
	Associate Professor	33	10.0
	Senior Professional Title	21	6.4
	Associate Senior Professional Title	74	22.5
	Intermediate Professional Title	99	30.1
	Below Intermediate Professional Title	92	28.0
Job Position	Senior Management	11	3.3
	Middle Management	70	21.3
	Frontline Management	145	44.1
	Other	103	31.3
Level of Familiarity	Very familiar	41	12.5
	Fairly familiar	106	32.2
	Somewhat familiar	120	36.5
	Not very familiar	62	18.8

4. Empirical Analysis of SEM

4.1. Reliability and Validity Testing

Reliability is a core indicator used to measure the stability, consistency, and reliability of measurement tools, mainly determined by Cronbach's alpha coefficient and composite reliability (CR). This paper uses SPSS26 software for analysis, and the analysis results are shown in Table 3. The alpha coefficients and CR values of each variable are all greater than 0.8, indicating that the reliability of this questionnaire is good and meets the requirements for subsequent in-depth analysis.

Table 3. Results of the Reliability and Validity Test.

Latent Variable	Observation Variable	Std Factor Loadings	CR	AVE	Cronbach's Alpha
Technical Factors A	A5	0.749	0.851	0.534	0.849
	A4	0.723			
	A3	0.728			
	A2	0.665			
	A1	0.784			
Organizational Factors B	B6	0.691	0.861	0.507	0.861
	B5	0.693			
	B4	0.729			
	B3	0.742			
	B2	0.731			
	B1	0.686			
Personnel Management Factors D	D4	0.747	0.828	0.546	0.826
	D3	0.77			
	D2	0.68			
	D1	0.756			
The Effects of Digital Transformation F	F1	0.772	0.844	0.575	0.844
	F2	0.751			
	F3	0.747			
	F4	0.763			
Environmental Factors C	C1	0.75	0.882	0.518	0.882
	C2	0.682			
	C3	0.73			
	C4	0.756			
	C5	0.706			
	C6	0.721			
	C7	0.688			
Enterprise Capability Factors E	E4	0.695	0.859	0.549	0.858
	E3	0.778			
	E2	0.742			
	E1	0.757			
	E5	0.729			

Validity analysis is used to assess the degree of fit between the actual performance of a measurement tool and the theoretical expectations. The higher the degree of fit between the two, the stronger the validity; conversely, it indicates insufficient validity. This study evaluated the suitability of the data for factor analysis through the KMO test and Bartlett's sphericity test. The results showed that the KMO value of the total scale was 0.957, far exceeding the acceptable level, and the KMO values of each dimension were all above 0.8, indicating that the data were suitable for extracting common factors.

Using SPSS26 statistical software, exploratory factor analysis (EFA) was conducted on 31 initial influencing variables (As shown in Table 1, 27 antecedent factors and 4 outcome indicators). The Harman single-factor test was applied to examine common method variance in the sample data. Analysis of the test sample data revealed that the maximum cumulative variance explained by any single factor prior to rotation was 40.729%, below the 50% threshold, confirming the absence of significant common method variance. All factor loading coefficients corresponding to the research variables exceeded 0.5, indicating that the design of the questionnaire in this survey met the requirements.

Subsequently, average variance extracted (AVE) and standardized factor loadings were used for validity testing. The research results showed that the standardized factor loadings of all variables were greater than 0.6, and the AVE values were above the acceptable level of 0.5. For discriminant validity, the square roots of the average variance extracted were compared with the correlation coefficients between each variable. The study indicated that the square roots of the AVE of all variables were greater than the correlation coefficients between other variables (Table 4), suggesting that all variables had good discriminant validity. Combining the above analysis, the model met the requirements of reliability and validity.

Table 4. Discriminant Validity Analysis Table.

Dimensionality	Enterprise Capability Factors E	Environmental Factor C	Personnel Management Factors D	Organizational Factors B	Technical Factor A	The Effect of Digital Transformation F
Enterprise Capability Factors E	0.741					
Environmental Factors C	0.669	0.720				
Personnel Management Factors D	0.619	0.657	0.739			
Organizational Factors B	0.671	0.720	0.685	0.712		
Technical Factors A	0.676	0.684	0.632	0.679	0.731	
The Effects of Digital Transformation F	0.671	0.694	0.677	0.709	0.695	0.758

4.2. Multicollinearity Test

Due to the high correlation level among latent variables, in order to eliminate the potential interference of multicollinearity, this study conducted a multicollinearity diagnosis on the technical factors, environmental factors, organizational factors, personnel management factors, and enterprise capability factors. The results show (Table 5) that the VIF values of the technical factors, organizational factors, environmental factors, personnel management factors, and enterprise capability factors are 1.933, 2.093, 2.088, 1.775, and 1.888, respectively, all of which are less than 5, and the tolerance is all greater than 0.2. This proves that there is no multicollinearity among the variables, maintaining good independence and effectively reflecting their respective contents. Therefore, it can be confirmed that there is no multicollinearity problem in this study, and it will not have a very serious impact on the results.

Table 5. Test for Multicollinearity.

Dimension	Tolerance	VIF
Technical	0.517	1.933
Organizational	0.478	2.093
Environmental	0.479	2.088
Personnel Management	0.563	1.775
Enterprise Capability	0.530	1.888

4.3. Path Analysis and Hypothesis Testing

Based on the above analysis results, it can be known that the model meets the requirements of reliability and validity. On this basis, the study further uses AMOS 28.0 statistical software to conduct path analysis and systematically test the rationality of the hypotheses. The specific test results are shown in Table 6.

Table 6. Summary Table of Path Coefficients.

Path Relationship	Std. Estimate	Unstd. Estimate	S.E.	C.R	*p*
F <---A	0.211	0.206	0.08	2.58	0.01
F <---B	0.205	0.197	0.085	2.326	0.02
F <---C	0.168	0.152	0.075	2.024	0.043
F <---D	0.196	0.18	0.072	2.498	0.012
F <---E	0.157	0.143	0.072	2.002	0.045

From the data values in the table, it can be found that technical factors A ($\beta = 0.211$, $p = 0.01$), organizational factors B ($\beta = 0.205$, $p = 0.02$), environmental factors C ($\beta = 0.168$, $p = 0.043$), personnel management factors D ($\beta = 0.196$, $p = 0.012$), and enterprise capability factors E ($\beta = 0.157$, $p = 0.045$) all have a significant positive impact on digital transformation. Their standardized path coefficients all pass the 0.05 significance level test. Hypotheses H1–H5 are all supported. The summary of the hypothesis verification results is shown in Table 7 below.

Table 7. Results of Hypothesis Verification.

Hypothesis	Specific Hypothetical Content	Verification Result
H1	Technical factors have a positive impact on the digital transformation effect of construction enterprises.	support
H2	Organizational factors have a positive impact on the effectiveness of digital transformation in construction enterprises	support
H3	Environmental factors have a positive impact on the effectiveness of digital transformation in construction enterprises.	support
H4	Personnel management factors have a positive impact on the effectiveness of digital transformation in construction enterprises.	support
H5	Enterprise capability factors have a positive impact on the effect of digital transformation in construction enterprises.	support

4.4. Results of SEM Analysis

The standardized path coefficients for the impact of technological, organizational, environmental, personnel management, and corporate capability factors on the effectiveness of digital transformation in construction enterprises are 0.211, 0.205, 0.168, 0.196, and 0.157, respectively. These factors are ranked in descending order of influence: technological factors, organizational factors, personnel management factors, environmental factors, and corporate capability factors. These influencing factors exert a direct impact on the outcomes of digital transformation in construction enterprises, exhibiting varying levels of influence intensity.

The application of technological tools provides the most fundamental support for construction enterprises' digital transformation. Through full-lifecycle collaboration and real-time data monitoring, it directly enhances project efficiency. Despite widespread adoption, digital technology advances slowly due to organizational resistance to change. Personnel management factors encompass skill upgrading, talent quality, and transformation willingness. Environmental factors include policy incentives, market competition, and supply chain pressures. Enterprise capability factors involve capital reserves, resource integration, digital agility, and risk tolerance.

A comprehensive analysis of these influencing factors reveals that construction enterprises should prioritize technological factors during digital transformation to ensure effective implementation and innovation. Concurrently, optimizing organizational structures and personnel management provides essential support for technology adoption and dissemination. Additionally, companies should actively leverage external environmental support to enhance their overall capabilities and achieve the anticipated outcomes of digital transformation. In summary, digital transformation in construction enterprises requires multi-factor coordination to avoid falling into a situation of "local optimization" in a single dimension.

5. Analysis of Fuzzy-Set Qualitative Comparative Analysis (fsQCA)

5.1. Data Calibration and Analysis of Necessity Conditions

As this study is a further validation based on the SEM, the antecedent variables and the collected data have already undergone reliability and validity analysis, as well as relevant data processing. Therefore, the current valid data can be directly calibrated. In line with the calibration standards for Likert five-point scale data in existing research, this paper adopts the common 95%, 50%, and 5% percentiles as anchor points to indirectly calibrate the data of the measurement variables, as shown in Table 8. Subsequently, the fsQCA3.0 software was used to calibrate the variable data, converting the original data into fuzzy sets between 0 and 1. To avoid potential analytical ambiguity when the membership score after calibration is strictly equal to 0.5 (i.e., the intersection point), the study slightly adjusted the values in the original data that were exactly at the intersection point, changing the membership score from 0.5 to 0.501.

Table 8. Calibration Anchor Points.

Calibrate Anchor Points	A	B	C	D	E	F
Fully Affiliated (95%)	4.60	4.67	4.57	4.75	4.80	4.63
Intersection (50%)	3.80	3.67	3.86	3.50	3.80	3.75
Completely Unaffiliated (5%)	2.00	2.00	1.93	1.75	1.90	1.88

After calibration, the necessity test was conducted on all antecedent variables and their negated forms. The results are shown in Table 9. As can be seen from the table, the consistency of all the condition variables is less than 0.9, indicating that no single condition variable can be a necessary condition for the generation of the transformation effect [44]. Digital transformation cannot be independently explained by a single condition but is driven by the interaction of multiple conditions. Therefore, the mechanism needs to be revealed through the analysis of conditional combination paths.

Table 9. Analysis of the Necessity Conditions of the Antecedent Variables.

Variable Name	F		~F	
	Consistency	Cover Degree	Consistency	Cover Degree
A	0.810346	0.739857	0.57602	0.559317
~A	0.517334	0.534303	0.732087	0.804124
B	0.832192	0.744914	0.594981	0.566409
~B	0.515609	0.54484	0.732045	0.822677
C	0.801226	0.751118	0.579093	0.577358
~C	0.549165	0.550926	0.750369	0.800588
D	0.821003	0.735006	0.603162	0.57428
~D	0.524472	0.554109	0.721678	0.810886
E	0.802362	0.730654	0.607513	0.588357
~E	0.547961	0.567615	0.721884	0.795272

5.2. Construction of Truth Table

The fsQCA 3.0 software was used to establish the truth table and calibrate the parameters. Due to the large sample characteristics of the research data in this paper, the threshold of case frequency was set to 3, and the original consistency threshold was set to 0.9 for standardizing the truth table. Referring to the research of scholars such as Cheng

Jianqing [45], the threshold of Pri consistency was set to 0.7. The condition combinations that met the above thresholds were assigned a value of 1, and the rest were assigned a value of 0. Eventually, a structured truth table suitable for Boolean minimization operation was generated.

5.3. Conditional Configuration Analysis

A standardized analysis was conducted on the reduced and refined truth table. In this study, all conditions in the standardized analysis process were set to default options, and a total of four configurations were identified. According to the commonly used representation method in actual research, the identified configurations were organized into the form shown in Table 10. As can be seen from Table 10, the consistency level of each configuration is above 0.8, and the overall coverage rate is 0.70, indicating a high explanatory power of the combination path.

Table 10. Combinations and Configurations of Influencing Factors for Digital Transformation.

Previous Cause and Condition	**High Digital Transformation Effectiveness**			
	Y1	**Y2**	**Y3**	**Y4**
Technology	●	●	●	●
Organization	●	•	●	
Environment	●	●		●
Personnel Management	•		●	•
Enterprise Competence		●	●	●
Consistency	0.903086	0.90584	0.90157	0.908581
Original Coverage Rate	0.617128	0.606403	0.608843	0.597861
Unique Coverage Rate	0.042048	0.0313227	0.0337626	0.0227802
Consistency of Solutions	0.862395			
Coverage of Solutions	0.704994			

"Blank" indicates that the condition in the configuration may or may not occur; ● represents the presence of a core condition, and • represents the presence of an auxiliary condition.

5.4. Results of fsQCA Analysis

Based on the analysis of Table 9, the antecedent condition configuration of the influencing factors of digital transformation in construction enterprises in this study can be divided into two types, namely, the technology-organization dual-driven type and the environment-capability leveraged type.

5.4.1. Technology-Organization Dual-Driven Type (Y1, Y3)

In this model, the common core conditions are technological factors and organizational factors. Technology is the "hard constraint" of transformation, determining the boundaries of an enterprise's capabilities. Technological elements not only provide digital tools but also reshape organizational logic through technological paradigm shifts. Organization is the "soft carrier" of transformation, determining the efficiency of technological value conversion. Organizational elements create organizational space for the in-depth application of technology through the reconstruction of organizational structure and mechanism innovation.

(1) Configuration Y1: Technology∗Organization∗Environment∗Personnel Management

The consistency of configuration Y1 is 0.90, and the original coverage rate is 0.62. The essence of digital transformation lies in the coordinated evolution of the technological system, organizational management, and institutional environment. Technology is not only the foundation of transformation but also a catalyst for organizational change and external adaptation. With its efficient and intelligent characteristics, technology offers construction enterprises the possibility to optimize processes, enhance efficiency, and boost competitiveness. Its impact is not isolated but deeply intertwined with organizational and environmental factors, forming a synergy mechanism of "technological support—organizational adaptation—environmental catalysis". Internally, organizations need to reach a high consensus on digital transformation, formulate clear strategic plans, and ensure the deep integration of technology and business needs. At the same time, an organizational culture that encourages innovation and tolerates failure should be fostered. The external environment, as another crucial variable, exerts pressure on construction enterprises through policy guidance, market demand, and other forms. This external pressure is not only a challenge to technology but also a test of organizational adaptability, driving them to accelerate the pace of digital transformation [46]. Under this mechanism, the driving force for digital transformation mainly comes from external environmental pressure, market competition, and the strategic determination of the organization, and does not overly rely on the deep alignment of personnel skills. The importance of employees' digital literacy is partially replaced, and their digital skills can be gradually adapted in practice.

(2) Configuration Y3: Technology∗Organization∗Personnel Management∗Enterprise Capability

The consistency of this configuration is 0.90, and the original coverage rate is 0.61. It emphasizes that regardless of whether the environmental factors are favorable or not, construction enterprises can rely on the organic combination of technology, organization, personnel management, and enterprise capabilities to achieve digital transformation. Technology tools and organizational elements constitute the infrastructure layer, while personnel management and enterprise capabilities form the strategic support layer. The four elements achieve dynamic upgrading through continuous interaction. Technological iteration forces the flattening of organizational structure, and organizational change provides institutional space for the application of new technologies [47]. Effective personnel management lays the foundation for the improvement of enterprise capabilities, and the enhancement of enterprise capabilities provides a better development platform for personnel management. This virtuous cycle enables construction enterprises to have sufficient talent reserves and strong internal capability support during the digital transformation process, laying a solid foundation for the success of the transformation.

5.4.2. Environment-Capability Leveraged Type

In this model, the common core conditions are technological factors, environmental factors, and enterprise capability factors. Since technological factors are the most fundamental condition for digital transformation, in this type of configuration, more attention is paid to the combination of the environment and enterprise capabilities. The external environment brings more opportunities and challenges. Construction enterprises, through their strong internal capabilities, transform environmental opportunities into replicable capability modules, thereby breaking through resource constraints.

(1) Configuration Y2: Technology∗Organization∗Environment∗Enterprise Capability

The consistency of this configuration is 0.91, and the original coverage rate is 0.61. This configuration indicates that during the digital transformation of construction enterprises, even if the organization's strategy, culture, and organizational structure are marginal conditions, the effect of digital transformation can still be enhanced when technology, external environment, and enterprise capabilities are well guaranteed. Advanced technology provides the tools and means needed for transformation, which can improve the efficiency and competitiveness of construction enterprises. Changes in the external environment, whether driven by policies or upgraded market demands, will become the external driving force for enterprise transformation. Under the guidance of policies, enterprises can keenly perceive the trend of industrial digitalization, more clearly grasp the direction of transformation, and utilize technological advantages to achieve industrial upgrading. At the same time, strong enterprise capabilities enable enterprises to flexibly respond to changes in the external environment, quickly adjust strategic directions, and effectively allocate resources to ensure the smooth implementation of transformation projects [48]. In this configuration, although organizational factors are not core conditions, they still profoundly influence the effect of digital transformation. The absence of organizational factors does not necessarily lead to transformation failure. Construction enterprises can still rely on existing funds and resources, leveraging the powerful synergy of technology, environment, and enterprise capabilities, to drive the digital transformation of construction enterprises to a higher level.

(2) Configuration Y4: Technology∗Environment∗Personnel Management∗Enterprise Capability

The consistency of this configuration is 0.91, and the original coverage rate is 0.60. This configuration indicates how construction enterprises should respond to the challenges during the transformation process when personnel management factors are present as auxiliary conditions. When there is a shortage of personnel with digital skills or when employees resist transformation, under the circumstances of policy promotion and market demand upgrading, construction enterprises can prioritize the adoption of mature and highly replicable standardized technologies. Through resource integration, market response, and standardized operations, they can achieve transformation and upgrading. Standardized technologies lower the threshold for personnel skills, converting human resources into scalable and replicable elements [49]. However, the non-core status of personnel management may lead to insufficient understanding of the technical connotations among grassroots personnel, who only master the operation interface but lack the ability to optimize parameters, ultimately resulting in a decline in the quality of technology implementation. Construction enterprises should utilize their own resource bases and capabilities to respond quickly to changes in the external environment and adjust their structures and processes to promote the implementation of technologies.

Based on the above analysis, it can be concluded that technological factors are the common core elements in all configurations, and the application and innovation of technology are the key drivers for the digital transformation of construction enterprises. In addition, organizational and personnel management appear in multiple configurations, indicating that they are also important influencing factors. Although the status of the environment and enterprise capabilities varies in different configurations, they also play a crucial role in specific contexts. The combination of factors in different configurations suggests that the influencing factors of the digital transformation of construction enterprises have a certain degree of context dependence. Under different enterprise backgrounds and market environments, the importance of each factor may vary.

6. Discussion

6.1. Theoretical Implication

Through a review of the literature on digital transformation, it was found that existing academic research is predominantly focused on the manufacturing sector. In the construction industry, existing research primarily examines the digital transformation processes and technology adoption behaviors of large state-owned construction companies, with a particular emphasis on the specific implementation strategies these companies employ to drive digital development. Research on the barriers to transformation is limited. Therefore, this study aims to break away from the traditional single-factor analysis paradigm, integrating the TOE theoretical framework with a configurational perspective to construct a systematic analytical model of the factors influencing digital transformation in construction companies, thereby enriching the theoretical research framework on digital transformation.

First, based on the TOE framework, this study further expands the dimensions influencing digital transformation in construction companies, identifying and validating five dimensions—technology, organization, environment, personnel management, and corporate capabilities—with a total of 27 specific influencing factors. SEM analysis results confirm that all five dimensions have a significant positive impact on the effectiveness of digital transformation in construction companies. This not only reinforces the universality of the TOE framework in explaining technology adoption and organizational change but also deepens the understanding of the complexity of digital transformation in traditional industries (especially labor-intensive construction) by introducing the dimensions of personnel management and corporate capabilities, thereby partially addressing the gap in existing research regarding the comprehensive impact of these specific factors.

Second, fsQCA was used to reveal the combinatorial configurations of antecedent conditions influencing the effectiveness of digital transformation in construction companies. The study found that digital transformation is not driven by a single factor but is the result of complex interactions among multiple factors, with no single necessary condition. Specifically, this study identified two major categories of combinatorial configurations: "technology-organization dual-driver type" and "environment-capability leverage type." This indicates that the mechanisms of factor interactions vary across different contexts.

Finally, through a complementary analysis of the two methods, this study further validated the central role of technological and organizational factors in the digital transformation of construction companies. SEM path coefficients showed that technological and organizational factors rank among the most influential. In the fsQCA analysis, technical and organizational factors also frequently appear as core conditions. This not only validates the theoretical view that technology serves as the "hard constraint" and organization as the "soft carrier" in digital transformation, but also emphasizes the critical supporting role of personnel management and corporate capabilities as the "people-centric" system engineering in the specific context of the construction industry.

6.2. Practical Implication

The SEM analysis results revealed that the path coefficients for technological factors, organizational factors, and personnel management factors were the highest. In the fSQCA analysis, these three factors also emerged as key elements across all four configurations. Consequently, this study recommends prioritizing these three elements in practical implementation to provide comprehensive guidance for construction enterprises, policymakers, and other stakeholders in effectively advancing the digital transformation of the construction industry.

Technical level: Construction enterprises undergoing digital transformation must establish a precise technology adaptation system: Utilize a three-dimensional matrix of "technology maturity-business alignment-economic viability" to screen technologies, prioritizing the deployment of intelligent construction equipment, engineering data platforms, and remote monitoring systems. Addressing industry-specific challenges, integrate BIM/ERP/IoT systems through a microservices architecture and standardized APIs to eliminate information silos and establish a continuous update mechanism. Simultaneously, develop a unified enterprise-level digital platform to integrate core business systems and build a data middle platform for multi-source data governance and service delivery. Deepen the application of IoT, AI, and other technologies, establish a dedicated technology assessment and assurance team, ultimately forming a data-driven, highly responsive digital foundation.

Organizational level: Construction enterprises advancing organizational digital transformation must develop clear, actionable strategic plans: Align with business characteristics and industry trends to define objectives, conduct comprehensive assessments of operational bottlenecks, data foundations, and digital capabilities, and establish phased implementation roadmaps. Simultaneously, they must innovate organizational culture, with leadership setting the example by fostering an atmosphere that encourages innovation, tolerates failure, and embraces openness and inclusivity. They should also optimize organizational structures, break down departmental silos, establish agile cross-functional teams and data circulation mechanisms, and empower frontline employees with decision-making authority to enhance responsiveness. This approach builds a digital organizational ecosystem characterized by strategic clarity, cultural alignment, and agile architecture, thereby supporting the fundamental implementation of transformation.

Personnel management level: Construction enterprises must establish a tiered, progressive digital competency development framework: Implement differentiated training programs for frontline workers (tool skills), mid-level managers (decision-making and collaboration), and senior leadership (strategic thinking). Establish incentive mechanisms by incorporating transformation outcomes into performance evaluations, creating an innovation tolerance framework, and establishing dedicated career advancement/compensation pathways to motivate and retain core talent. Utilize gamified learning platforms and psychological support to enhance frontline employees' (especially older workers) willingness to embrace change and mitigate resistance. Simultaneously, form cross-departmental digital core teams, recruit high-end technical talent, and leverage industry-academia-research resources to explore cutting-edge domains. Ultimately, build a comprehensive talent pipeline and capability system to underpin the transformation.

Finally, the combination configurations revealed by this study provide companies with more targeted transformation path options. "Technology-Organization Dual-Driven" enterprises should focus on the deep integration and synergistic evolution of technology and organizational structures. This means considering the alignment of technology selection with organizational strategy and culture, and creating a favorable environment for technology application through organizational transformation. "Environment-Capability Leveraged" enterprises can instead prioritize leveraging external environmental opportunities (such as policy support and upgraded market demand) and their own robust enterprise capabilities. While such enterprises may have shortcomings in personnel management or organizational structure, they can prioritize the adoption of mature standardized technologies and leverage their resource integration and market response capabilities to drive transformation.

In summary, construction enterprises should flexibly select and adjust their digital transformation strategies based on their technological foundation, organizational characteristics, talent reserves, enterprise capabilities, and external environment to achieve the best transformation outcomes.

6.3. Limitations and Future Research Directions

The findings of this study have certain theoretical significance and practical implications. However, there are still many issues that were not fully considered or thoroughly investigated during the research process, and the study has certain limitations.

First, the digital transformation of construction companies is a dynamic and complex system with diverse and interdependent characteristics. However, subjective biases may limit the identification process, preventing the inclusion of all influencing factors. Therefore, it is necessary to conduct a detailed analysis of the influencing factors. Additionally, the sample data in this study were collected through a questionnaire distributed via Questionnaire Star, and the subjective nature of the respondents' responses may have reduced the generalizability of the research conclusions. In future studies, researchers could group samples by company size or qualifications for comparison, or incorporate longitudinal tracking data to validate the generalizability of the conclusions.

Second, this study explored the impact of five variables—technology, organization, environment, personnel management, and corporate capabilities—on the digital transformation of construction companies based on previous research, potentially overlooking the existence of other important variables. The research model did not introduce mediating variables or moderating variables, ignoring the influence of mediating or moderating variables on other research variables. In future research, more antecedent variables or a deeper exploration of the effects of mediating and moderating variables could be considered to construct a more comprehensive and reasonable research model.

Finally, the policy recommendations proposed in this study are derived from model analysis results and have not been validated through industry-specific projects. Therefore, it is recommended that subsequent research combine actual project cases to further refine the proposed solutions.

7. Conclusions

Based on the current situation of digital transformation in construction enterprises, this paper, on the basis of relevant literature and theories, uses the SEM to verify the linear relationship between the influence of technology, organization, environment, personnel management, and enterprise capabilities on the digital transformation of construction enterprises. Based on this, the study further uses fsQCA to analyze the combination configuration of antecedents that affect the digital transformation of construction enterprises and the interaction effects among various factors. The specific conclusions obtained are as follows:

First, using literature review and expert interviews, based on TOE theory, 27 specific influencing factors were identified from five dimensions: technical factors, organizational factors, environmental factors, enterprise capability factors, and personnel management factors. A list of influencing factors for the digital transformation of construction enterprises was constructed.

Second, a structural equation model of the influencing factors of digital transformation in construction enterprises was constructed. Empirical evidence shows that the Five Dimensions all have a positive impact on the effectiveness of digital transformation in construction enterprises, and exhibit differentiated levels of influence intensity.

Finally, fsQCA was used to conduct a configurational analysis of the factors influencing the digital transformation of construction companies. The pre-conditions for the digital transformation of construction companies can be categorized into two types: the technology-organization dual-driver type and the environment-capability leverage type.

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