Proceedings of the 10th International Conference on Economic Management and Green Development
DOI: 10.54254/2754-1169/2026.38645

Multiple Pathways for High-Level Development of Construction Industrialization Empowered by Technology-Resource-Economy——A Dynamic QCA Analysis Based on Panel Data of Sichuan Province

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Abstract. Compared with the traditional construction industry, construction industrialization features low carbon emissions, high efficiency and environmental friendliness, which satisfies China's development requirements in the new era. Nevertheless, the unbalanced development of construction industrialization in China remains prominent at present. Located in the southwest of China, Sichuan Province needs further improvement in construction industrialization when compared with more developed regions. Therefore, based on practical case analysis of Sichuan Province, this paper sorts out and summarizes six factors affecting the development of construction industrialization. It adopts the fuzzy-set qualitative comparative analysis (fsQCA) method to examine the impacts of different factor configurations on the development level of construction industrialization, and explores effective pathways suitable for the development of construction industrialization in this province.

Keywords: fuzzy-set qualitative comparative analysis (fsQCA), construction industrialization, pathway research, high-quality development

1. Introduction

According to the report of the International Energy Research Center, the global construction industry accounts for 40% of total carbon emissions. Surveys and research by the World Bank suggest that 70% of emission reduction potential lies in building energy conservation if energy saving and emission reduction targets are to be achieved before 2030. The transformation of construction enterprises is a strategic change made to adapt to market competition, address environmental challenges and realize sustainable development. It aims to improve enterprise competitiveness, create higher value and achieve success in the new market environment [1]. These problems and contradictions urge the construction industry to pursue transformation urgently, and change its status of high energy consumption, low development level and imbalance through industrialized and modernized approaches.

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DOI: 10.54254/2754-1169/2026.38645

Since the concept of construction industrialization was put forward, many scholars have carried out research within their respective fields. When exploring the energy efficiency of the construction industry, Abbood A W et al. adopted *EnergyPlus* software to compare energy efficiency under traditional construction methods and construction industrialization methods. The results show that the production mode of construction industrialization consumes less energy than traditional construction, with energy consumption in winter and summer reaching merely 62.68% and 34.64% of that of the traditional construction mode [2]. After studying developers' perceptions of adopting industrialized building models, Steinhardt D A et al. argue that it is essential to establish a complete and unified interest network and raise awareness of construction industrialization for its development [3]. Li Qihui, Wang Dedong et al. hold that establishing the concept of integrated development of industrialization and industrialization is the fundamental guarantee for the high-level development of new-type construction industrialization [4]. Han Yanhu, Luo Fuzhou remind researchers to break through the traditional engineering management paradigm and explore new organizational modes such as modular division of labor and digital collaboration from the perspective of industrial ecology [5]. Especially under the background of rapid iteration of intelligent construction technologies, how to realize technology diffusion and value appreciation through industrial chain restructuring has become a core proposition determining the quality of high-level development of construction industrialization. Ji Yingbo, Duan Zhaohui et al. analyze regional differences in the development of prefabricated buildings in China from static efficiency and dynamic efficiency respectively [6]. Shang Mei, Wang Ganggang believe that the main influencing factors of carbon emissions in the construction industry are the intensity effect of energy structure, the intensity effect of energy consumption and the output scale effect, and accordingly propose low-carbon development pathways for various provinces [7]. Ang Yu Qian, Berzolla Zachary Michael et al. construct an urban building energy model (UBEM) based on networks, and identify technical pathways for carbon emission reduction using the urban building energy model rapidly generated by this model [8]. By analyzing the first-mover advantages of the passive ultra-low energy building industry in Hebei Province, Xu Shuangjun, Zhu Tianzhi et al. study large-scale and high-quality innovative development pathways of Hebei's passive ultra-low energy building industry under the dual-carbon goal from multiple dimensions: "government-enterprise-resident", "technology-health-culture-building" and "project-tourism-rural area" [9]. From the stakeholder perspective, Liu Ge and Fu Yingjie analyze problems existing in the operation and management of green buildings in China, and discuss innovative pathways of "full-process participation" and "multi-agent collaboration" in green building operation and management [10].

Most existing studies focus on how to realize construction industrialization and obstacles encountered in its high-level development. They adopt traditional quantitative analysis and view variable relationships from an isolated perspective. Few studies explore influencing factors for the high-level development of construction industrialization based on configurational theory and the QCA method. Therefore, this paper takes the configurational perspective as a breakthrough to study high-quality development pathways of construction industrialization. Taking Sichuan Province as the research object, this paper uses the fuzzy-set qualitative comparative analysis (fsQCA) method to investigate the impacts of different factor configurations on the high-level development of construction industrialization, and explores effective pathways for the high-level development of construction industrialization in Sichuan Province.

DOI: 10.54254/2754-1169/2026.38645

2. Research design and data arrangement

2.1. Research method

This paper comprehensively applies the fsQCA method to explore the necessary and sufficient causal relationships of the research object. This mixed method combines the strengths of qualitative and quantitative analysis to more fully study the impacts of government support, economic factors and market demand on the industrialization of construction enterprises. Logical comparisons of multiple conditions and outcomes are carried out to identify combinations of conditions that produce specific outcomes, and further explore the complex causal mechanisms affecting the industrialization of construction enterprises.

2.2. Data sources

This study uses panel data of Sichuan Province from 2007 to 2023 as research samples. Data are obtained from *Sichuan Statistical Yearbook*, the National Bureau of Statistics, the Department of Housing and Urban-Rural Development of Sichuan Province, and other public data released by national government websites. Due to the lack of historical statistical data on the area of prefabricated buildings, the annual newly-started target of prefabricated buildings formulated by the Department of Housing and Urban-Rural Development of Sichuan Province is adopted as a substitute. Data gaps in certain years are filled by linear interpolation.

2.3. Variable measurement

2.3.1. Outcome variable

Combined with studies of multiple scholars, the entropy method is used to measure the industrialization development level of construction enterprises from three dimensions: development scale, innovation capacity and development potential. The specific measurement indicators are shown in Table 1.

Table 1. Outcome variable

Outcome Variable	Dimension	Measurement Indicator
High-level development of construction industrialization	Development scale	Number of enterprises related to construction industrialization (unit)
		Total assets of construction enterprises (10,000 yuan)
		Floor area of buildings under construction (10,000 square meters)
		Newly-started floor area of prefabricated buildings (10,000 square meters)

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Table 1. (continued)

High-level development of construction industrialization	Innovation capacity	Number of national-level industrial bases for prefabricated buildings (unit)
		Number of provincial-level industrial bases for prefabricated buildings (unit)
		Number of newly added patents related to construction industrialization (unit)
	Development potential	Technical equipment rate (yuan per person)
		Power assembly rate (kilowatt per person)
		Labor productivity of total construction output value (yuan per person)
		Year-end number of employees in construction industry (10,000 persons)
		Profit margin of construction enterprises (%)
		Total profit and tax of construction enterprises (10,000 yuan)

2.3.2. Conditional variables

Based on research on influencing factors of prefabricated buildings and construction industry development, as well as domestic and foreign studies on high-level development of construction industrialization, six influencing factors are selected as conditional variables: government support, economic factors, construction cost, industrial technical equipment level, population concentration degree and market demand, as shown in Table 2.

Table 2. Conditional variables

Variable Category	Layer	Variable Name	Measurement Indicator
Conditional Variables	Technology	Industrial technical equipment level	Total number of self-owned construction machinery and equipment of construction enterprises at year-end
	Resource	Government support	Policy support intensity
		Population concentration degree	Population density

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Table 2. (continued)

Conditional Variables	Resource	Market demand	Floor area of newly started buildings in the current year
	Economy	Construction cost	Construction cost of completed buildings
		Economic factors	Per capita regional gross domestic product

2.4. Variable calibration

For comparative analysis, set membership scores are assigned to all cases for calibration. The calibration results of each indicator are shown in Table 3.

Table 3. Variable calibration

Year	Variable Type						
	Outcome Variable	Conditional Variables					
	High-level development of construction industrialization	Policy support	Economic factors	Construction cost	Industrial technical equipment level	Population concentration degree	Market demand
2007	0.03	0.2	0.04	0.03	0.8	0.11	0.05
2008	0.05	0.57	0.05	0.05	0.8	0.18	0.04
2009	0.05	0.06	0.06	0.09	0.8	0.25	0.05
2010	0.07	0.2	0.1	0.14	0.39	0.26	0.22
2011	0.10	0.5	0.18	0.22	0.46	0.31	0.31
2012	0.29	0.2	0.26	0.26	0.5	0.44	0.30
2013	0.38	0.71	0.35	0.38	0.63	0.50	0.59
2014	0.65	0.86	0.45	0.45	0.74	0.66	0.75
2015	0.50	0.92	0.50	0.53	0.49	0.01	0.50
2016	0.50	0.95	0.57	0.53	0.58	0.50	0.69
2017	0.58	0.95	0.70	0.50	0.95	0.56	0.77
2018	0.91	0.89	0.80	0.56	0.97	0.66	0.95
2019	0.88	0.65	0.85	0.76	0.95	0.64	0.97
2020	0.94	0.09	0.88	0.90	0.42	0.74	0.94
2021	0.95	0.06	0.93	0.94	0.20	0.88	0.77
2022	0.91	0.06	0.95	0.96	0.06	0.96	0.30
2023	0.97	0.02	0.97	0.95	0.02	0.95	0.07

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3. Empirical analysis

3.1. Necessity analysis

In the necessary condition test of the six conditional variables (results shown in Table 4), none of the conditional variables have a consistency level higher than 0.9. Therefore, among the six selected conditional variables, there exists no necessary condition for the high-level development of construction industrialization. In addition, this paper also conducts the necessary condition test for the outcome "~ high-level development of construction industrialization". The results show that no conditional variable with consistency level exceeding 0.9 is found, which indicates that no single conditional variable can cause causal changes to the high-level development of construction industrialization.

Table 4. Results of necessary condition analysis

Variable Name	Outcome Variable			
	High-level development of construction industrialization		~ High-level development of construction industrialization	
	Consistency	Coverage	Consistency	Coverage
Policy support	0.557078	0.618504	0.548544	0.572877
~ Policy support	0.615297	0.591657	0.634709	0.574094
Economic factors	0.895206	0.878333	0.394417	0.376157
~ Economic factors	0.384703	0.40311	0.886311	0.802584
Construction cost	0.892968	0.868788	0.410194	0.409697
~ Construction cost	0.444064	0.444571	0.858738	0.602857
Industrial technical equipment level	0.599315	0.566955	0.792476	0.705184
~ Industrial technical equipment level	0.688356	0.77907	0.513350	0.546512
Population concentration degree	0.851598	0.867442	0.465311	0.437209
~ Population concentration degree	0.447489	0.466667	0.861650	0.845238
Market demand	0.805936	0.853688	0.457524	0.455865
~ Market demand	0.486301	0.487972	0.853155	0.805269

DOI: 10.54254/2754-1169/2026.38645

3.2. Configurational analysis

This study adopts the fsQCA method to reveal the causal mechanisms and correlations that produce high-level development and non-high-level development of construction industrialization under different condition combinations. The detailed results are shown in Table 5.

Table 5. Configurations for high-level / non-high-level development of construction industrialization

Antecedent Conditions(Condition Configurations)	High-level development of construction industrialization		~ High-level development of construction industrialization	
	S_1	S_2	S_3	S_4
Policy support	⊗	●	⊗	
Economic factors	●	●	⊗	⊗
Construction cost	●	●	⊗	⊗
Industrial technical equipment level	⊗			●
Population concentration degree	●	●	⊗	⊗
Market demand		●		
Consistency	0.969136	0.971279	0.979508	0.969889
Raw coverage	0.537671	0.424658	0.580097	0.742718
Solution consistency	0.978417		0.971935	
Solution coverage	0.776256		0.798544	

● denotes the presence of a core condition

⊗ denotes the absence of a core condition

● denotes the presence of a peripheral condition

⊗ denotes the absence of a peripheral condition

Blank cells indicate that the condition is irrelevant to the outcome

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The results show there are two configurational paths for the high-level development of construction industrialization. The consistency level of both paths exceeds 0.9, far above the minimum interpretable threshold and reaching a high standard. It indicates that the obtained configurational results can explain at least 97% of the variance in the outcome variable. Meanwhile, its solution coverage stands at 0.776256, meaning the configurational results for high-level construction industrialization development can explain approximately 78% of cases.

S_1: Economy-cost driven type. It is a construction industrialization development model formed under specific regional circumstances. Its core logic is to promote industrialization via economic vitality and cost control rather than relying on policy support or technological upgrading. Governments in certain developing regions may fail to provide tax incentives, R&D subsidies for technology or standardization guidance due to fiscal pressure or limited administrative capacity. As a result, enterprises must operate independently and tend to rely on existing low-cost resources instead of innovation, leading to low product added value and market competitiveness limited to the mid-to-low-end market.

S_2: Light-technology and economy-oriented type. Its core is to achieve rapid development through economic vitality and cost control, suitable for regions with limited policy and technical resources. With external support from population concentration and market demand, industrial transformation can be realized under existing technical conditions.

S_3: Shallow application of technical equipment and lack of systematic conditional support. Although the industrial technical equipment level is marked as "present", its practical effect is constrained by critical conditions including government support, economic vitality and construction cost. This ultimately creates a dual dilemma of "isolated technology" and "involution in development". If governments lack policy guidance, enterprises will have no external incentives for technological upgrading. Insufficient regional economic vitality restricts the investment capacity of private sectors; enterprises can hardly afford purchases of high-end equipment or recruitment of technical talents. Dispersed population distribution leads to insufficient market demand and makes economies of scale unattainable.

S_4: Inefficient technology-dependent type. This path presents a construction industrialization development model of "available technology without benefits". Its core features are as follows: industrial technical equipment level exists as a peripheral condition, yet key driving forces such as economic vitality and construction cost are missing. Coupled with insufficient market demand caused by scattered population, a vicious cycle of idle technology and inefficient development is formed. Essentially, it is a "technology bubble trap": without economic backing and market demand, industrialization technology becomes formal input instead of a real driving force.

4. Conclusions and suggestions

(1) Make up for shortcomings in technology and policies. While maintaining cost advantages, introduce applicable technologies in phases. Enterprises should actively communicate with local governments to obtain support from regional pilot policies, push governments to introduce tax reduction or land preferential policies, and translate corporate practices into policy references. Meanwhile, human resources and technical reserves need to be cultivated. Improve employees' skills through university-enterprise cooperation or internal training to offset the inadequacy of industrial technical equipment level. Regularly assess the technological development trend of the industry to avoid being eliminated by the market due to path dependence.

(2) Build sustainable barriers for cost advantages. Establish a regional cost-sharing mechanism for industrialization, encourage leading enterprises to extend upstream or integrate downstream, and

DOI: 10.54254/2754-1169/2026.38645

cut costs through full industrial chain control. Activate the multiplier effect of policies and markets, build an evaluation platform for industrialized buildings with consumer participation, and take user experience as one direction for corporate technical improvement. Especially for high-density cities, market acceptance can be fostered via price concessions. Enterprises should monitor indicators such as regional GDP growth rate and fluctuations in building material prices in real time, and set threshold values to trigger response plans.

(3) Achieve transformation and upgrading through "exchanging technology for resources". Explore hybrid driving modes of "technology + policy" or "technology + market". Adjacent counties can jointly build and share industrial production bases to raise equipment utilization rate and supply chain efficiency. Develop light prefabrication technologies suitable for low-density regions. Through systematic improvement of weak links, promote technology to shift from "formal existence" to "effective driving".

The industrialization of construction enterprises is not only a necessary choice to cope with resource and environmental constraints, but also an inevitable outcome of the coordinated interaction of policies, technologies and industrial ecology. Systematic coordination among technology, economy, market and policy is required. Technology provides tools and methods; economy determines the efficiency of resource allocation; market shapes demand orientation; policy builds institutional environment. None of the four can be omitted. In the future, it is necessary to further strengthen the standard system, accelerate the transformation of industry-university-research achievements, and improve talent pipelines, so as to realize the deep integration of industrialization and digitalization and establish a sustainable new paradigm for the construction industry.

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