Research on Influencing Factors of Science and Technology Innovation in Construction Enterprises Based on DEMATEL-AISM

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Abstract. Numerous factors influence technological innovation in construction enterprises. Through literature review and expert surveys, this study identifies and summarizes eight influencing factors on technological innovation in existing construction enterprises. A DEMATEL-AISM model is constructed to establish the hierarchical structure and causal pathways of the influencing factors. The research reveals that these factors can be categorized into five layers.The formulation and implementation of enterprise innovation strategy is the root factor, and the centrality is also the largest. Meanwhile, the growth rate of operating profit is identified as a result factor.Based on the results of the study, relevant recommendations are made, which are expected to contribute to the high-quality development of the construction industry.

Keywords: DEMATEL, adversarial interpretation structure model, science and technology innovation, influencing factor.

1 INTRODUCTION

With the continuous progress and climb of China's economy, the achievements of all industries in China are obvious , among which the construction industry is developing extremely fast.In 2022, the total output value of the China's construction industry was 3,1197.984 billion RMB, accounting for 26% of the GDP, and the added value of the construction industry accounted for 6.9% of the GDP[1] .

Thirteen Chinese ministries and commissions jointly issued the "Guiding Opinions on Promoting the Synergistic Development of Intelligent Manufacturing and Industrialization of Construction" in July 2020, which clearly defined the development goals by 2025, including cultivating a number of leading intelligent manufacturing enterprises, guiding and promoting the transformation and upgrading of small and medium-sized enterprises to intelligent manufacturing, and creating an upgraded version of "China's Intelligent Manufacturing".Intelligent manufacturing is inseparable from scientific and technological innovation, so it is of great significance to study the influencing factors of scientific and technological innovation in the construction industry. With

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the continuous promotion of national policies, construction enterprises gradually emphasize the role of scientific and technological innovation in improving core competitiveness. By effectively refining the influencing factors of science and technology innovation of construction enterprises, and sorting out the relationship between each influencing factor, it helps to efficiently promote the construction industry to improve the ability of science and technology innovation in a focused way, activate its enthusiasm for science and technology innovation, and promote the sustainable and healthy development of the construction industry[2] .

2 OVERVIEW OF RESEARCH ON INFLUENCING FACTORS OF TECHNOLOGICAL INNOVATION IN CONSTRUCTION ENTERPRISES

Scholars have gradually carried out research on the influencing factors of science and technology innovation in the construction industry. Wang[3]simulated the innovation process of 57 large listed construction companies and found that company size is an important influencing factor, which has a strong positive impact on innovation investment and performance. Li[4]studied the impact on science and technology innovation of construction enterprises from three aspects: market, government and technology, and found that the level of development of the construction industry and the openness of the market have a positive impact on the innovation of enterprises, while the impact of social innovation ability and the level of public education is not significant. Chen Ke et al[5] analyzed the level of science and technology innovation in China's construction industry from 2009 to 2018 by looking for influencing factors in terms of inputs, outputs and economic benefits. Meanwhile, problems are identified and suggestions are made by comparing the construction industry with other industries horizontally to promote the development of the construction industry. Scholar Xu Liping[6] thought that the influencing factors of science and technology innovation in construction enterprises are six items, including input of resource, R&D, production, output of results, marketing and management ability. Jin Yuan et al[7] studied the technological level of some listed construction enterprises in 2019. Yu Yongze[8] pointed out that the degree of marketing , government policy support, enterprise scale and performance all affect industrial technological innovation to different degrees.

In summary, the current research on the influence factors of construction enterprise science and technology innovation at home and abroad is not deep enough, most of them use the construction of evaluation index system to point out the influencing factors, and there is a lack of relevant in-depth research on the relationship between the influencing factors of scientific and technological innovation of construction enterprises. Based on the existing research, this paper firstly identifies 8 factors influencing scientific and technological innovation of construction enterprises by combing and analyzing existing policies and literature, combined with questionnaire survey and expert interview methods, and then builds a multi-level hierarchical structure model through DEMATEL-AISM model to explore the relationship and action path between various factors. The corresponding countermeasures and suggestions are put forward. Through the in-depth discussion of this study, we hope to make positive contributions to the healthy and high-quality development of the construction industry.

3 CONSTRUCTION OF INFLUENCING FACTORS OF TECHNOLOGICAL INNOVATION IN CONSTRUCTION ENTERPRISES

3.1 Literature-Based Identification of Influencing Factors

In this paper, the keywords "technological innovation of construction enterprises" and "influencing factors" are searched on CNKI and Web of Science.A preliminary list was sorted out by combing relevant literature, including 14 influencing factors, as shown in Table 1.Through literature review, we can see that previous studies basically include innovation input and innovation output.The investment in scientific and technological innovation represents the basic resources provided by construction enterprises for scientific and technological innovation activities, including economic capital, intellectual resources and talents. And the innovation output is the substantive results of the construction enterprise's scientific and technological activities,and also a clear demonstration of the level of technological innovation of the enterprise.The positive interaction and interaction of input and output not only promotes the continuous improvement of innovation strength of construction enterprises, but promotes the development of the entire industry. The organizational management should also be an essential factor, which reflects whether the manager has an open and positive mode of thinking. Only by maintaining an open and adventurous organizational management mode can better promote the construction enterprises to adapt to market changes, the courage to innovate and change, to achieve a higher level of sustainable development.

Table 1. Tale1. Influencing factors based on literature identification

Influencing factors	Sources (relevant literature)
The growth rate of research funding	Literature [10],[13],[15]
The level of investment in scientific research funds	Literature[9],[10],[11],[12],[14]
The per capita income of researchers	Literature [9],[14],[15]
The per capita allocation of R&D funds	Literature [10],[14],[15]
The proportion of researchers	Literature[10],[11],[12],[13],[15]
The proportion of personnel with senior professional titles	Literature [14],[15]
Corporate Innovation Culture	Literature [9],[15]
Number of published papers and actual patents by companies	Literature[10],[11],[12],[13],[14],[15]
Technical equipment situation	Literature [9],[13],[15]
The growth rate of operating profit	Literature [10],[11],[12],[15]
The perfection of enterprise science and technology development facilities	Literature [9],[11],[14]
Leaders' ability to manage innovation	Literature [9],[14]
The formulation and implementation of enterprise innovation strategy	Literature [9],[13]
The situation of informatization management	Literature [9],[13]

3.2 List of Influencing Factors

Through a questionnaire survey, a preliminary list of the factors influencing the technological innovation of construction enterprises identified based on the literature was sent to experts and scholars in the field, and finally 16 rounds of consultation and feedback were conducted. According to the opinions of experts, the influencing factors at different levels are screened and adjusted, and eight factors affecting the technological innovation of construction enterprises are finally sorted out from four levels: fund inputs, talent inputs, achievement outputs and organization management. The final list of influencing factors is shown in Table 2.

Table 2. Final list of influencing factors

factor level	factor	Factor No.
Fund inputs	The growth rate of research funding	D1
	The level of investment in scientific research funds	D2
Talent inputs	The proportion of personnel with senior professional titles	D3
	The proportion of researchers	D4
Innovation outputs	Patents and awards obtained by enterprises	D5
	The growth rate of operating profit	D6
Organizational Management	The formulation and implementation of enterprise innovation strategy	D7
	Leaders' ability to manage innovation	D8

4 ASSESSMENT OF INFLUENCING FACTORS OF SCIENCE AND TECHNOLOGY INNOVATION IN CONSTRUCTION ENTERPRISES BASED ON DEMATEL-AISM MODEL

4.1 Construction of DEMATEL-AISM Model

Based on the above mentioned factors of technological innovation in construction enterprises, DEMATEL method is used to carry out matrix operation to reveal the influence intensity and causality among indicators. However, this method cannot clearly determine the structure level of each basic element in the system. In contrast, the AISM method builds a set of opposing hierarchical topology to identify active factors. Therefore, combining the DEMATEL and AISM models, we have been able to comprehensively evaluate and analyze the underlying factors in intricate systems and effectively delineate the hierarchical structure. Figure 1 shows the specific model framework in detail.

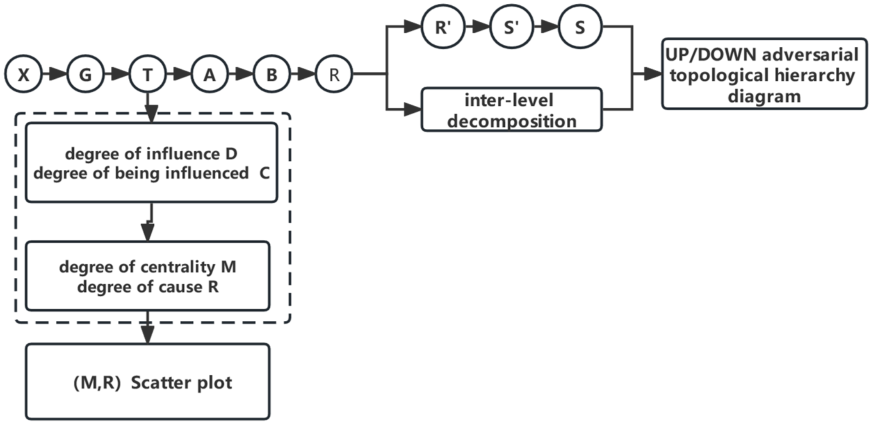

Fig. 1. Diagrams of model and framework

The DEMATEL-AISM model is constructed as follows:

Step 1: Calculate the integrated impact matrix T. Firstly, the factors in Table 2 were quantified and scored by the expert interview method, and the initial direct impact matrix X was obtained by sorting and summarizing. Then, according to the steps shown in Fig. 2, MATLAB was used to calculate the normalized impact matrix G and integrated impact matrix T.

Fig. 2. Construction process of integrated impact matrix

$$G = \frac{X}{MAX \sum_{j=1}^{n} S_{ij}} (1 \le i \le n) \quad (1)$$

$$\mathrm{T} = \mathrm{G}^1 + \mathrm{G}^2 + \mathrm{G}^3 + \cdots + \mathrm{G}^n = \mathrm{G}(\mathrm{I} - \mathrm{G})^{-1} \quad (2)$$

Step 2: Calculate the degree of influence d_i, the degree of being influenced c_i, the degree of centrality M_i and the degree of cause R_i of the factors:

$$d_i = \sum_{j=1}^{n} t_{ij} \; (1 \le i \le n) \quad (3)$$

$$c_i = \sum_{i=1}^{n} t_{ij} \; (1 \le i \le n) \quad (4)$$

$$M_i = d_i + c_i \quad (5)$$

$$R_i = d_i - c_i \quad (6)$$

Step 3:Construct the adjacency matrix A and reachable matrix R. In this step,a threshold λ is introduced.It is calculated by the integrated impact matrix T.$\lambda = \overline{x} + \sigma$,$\overline{x}$ is the average value of the elements in the T matrix, σ is the population standard deviation of the elements in the T matrix.Based on the threshold λ, the reachable matrix R is determined, as shown in Equation (7),(8), (9). E denotes the unit matrix.

$$A = \begin{cases} A_{ij} = 0, & t_{ij} < \lambda \\ A_{ij} = 1, & t_{ij} \geq \lambda \end{cases} \tag{7}$$

$$B = A + E \tag{8}$$

$$B^{k-1} \neq B^k = B^{k+1} = R \tag{9}$$

Step 4:Construct the skeleton matrix S.After the point and edge reduction calculation,matrix R' is obtained.The matrix S' is derived after keeping the longest path,and d the skeleton matrix S is adjusted after the shortest path.

$$S' = (R' - E)^2 - E \tag{10}$$

Step 5:Regional decomposition and inter-level decomposition.In the row of factors, all elements of value 1 form the reachable set of S_i, denoted $R(S_i)$.In the column of factors, all elements of value 1 form the antecedent set of S_i, denoted $Q(S_i)$.And the common set T(Si)=R(Si)∩Q(Si).And the adversarial hierarchy is divided by the result-first and cause-first rules, respectively.

$$\begin{cases} R(S_i) = T(S_i), \text{Result First} \\ Q(S_i) = T(S_i), \text{Cause First} \end{cases} \tag{11}$$

4.2 Results of DEMATEL-AISM model

After the calculation of equations(1)-(2),the integrated impact matrix T is constructed.

$$T = \begin{bmatrix} 0.0195 & 0.0013 & 0.0013 & 0.0013 & 0.2725 & 0.0747 & 0.0050 & 0.0053 \\ 0.2719 & 0.0004 & 0.0004 & 0.0004 & 0.0727 & 0.0199 & 0.0013 & 0.0014 \\ 0.0213 & 0.0027 & 0.0027 & 0.2694 & 0.2780 & 0.1505 & 0.0100 & 0.0819 \\ 0.0248 & 0.0063 & 0.0063 & 0.0064 & 0.2763 & 0.3544 & 0.0236 & 0.2920 \\ 0.0732 & 0.0050 & 0.0050 & 0.0051 & 0.0219 & 0.2801 & 0.0187 & 0.0200 \\ 0.0196 & 0.0183 & 0.0183 & 0.0186 & 0.0139 & 0.0317 & 0.0688 & 0.0738 \\ 0.2883 & 0.2702 & 0.2702 & 0.2747 & 0.2042 & 0.2000 & 0.0133 & 0.0866 \\ 0.0052 & 0.0049 & 0.0049 & 0.0050 & 0.0037 & 0.2751 & 0.0183 & 0.0197 \end{bmatrix}$$

After the calculation of equations(3)-(6), d_i;c_i;M_i;$R_i$are obtained. The cause-result graph of each factor is drawn according to cause degree values and the centrality, as Figure 3 shown.

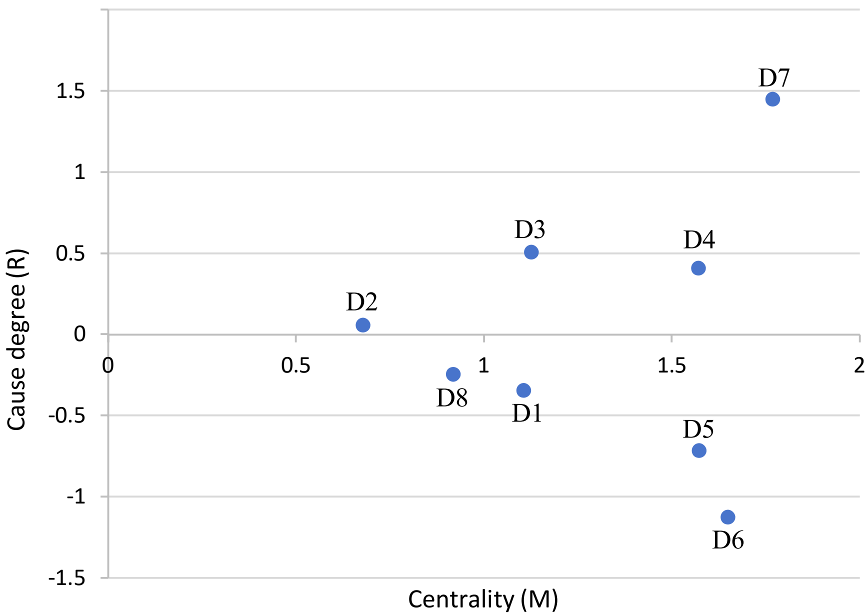

Fig. 3. Coordinate diagram of centrality-causation degree of each factor

After the calculation of equations(7)-(10), the skeleton matrix S of each influence factor is obtained.

$$S = \begin{bmatrix} 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix}$$

The reachable set, antecedent set and common set of each influence factor were derived by using equation(11),the hierarchical division results of UP/DOWN confrontation are shown in Table 3.

Table 3. Hierarchical division results of UP/DOWN confrontation

Levels	Result first——UP type	Cause first——DOWN type
Level1	D6	D6
Level2	D5;D8	D5;D8
Level3	D1,D4	D1,D4
Level4	D2,D3	D2,D3
Level5	D7	D7

According to the results of hierarchy division, the factors at each level of the UP and DOWN hierarchy results are the same, which means that the system does not contain "active elements". Therefore, this system is topologically rigid. In this paper, the system is stable, the connections between nodes are clear, and the reliability is high.

Combining the skeleton matrix S and the results of UP/DOWN adversarial hierarchy division, the structure models are plotted separately, as shown in Figures 4:

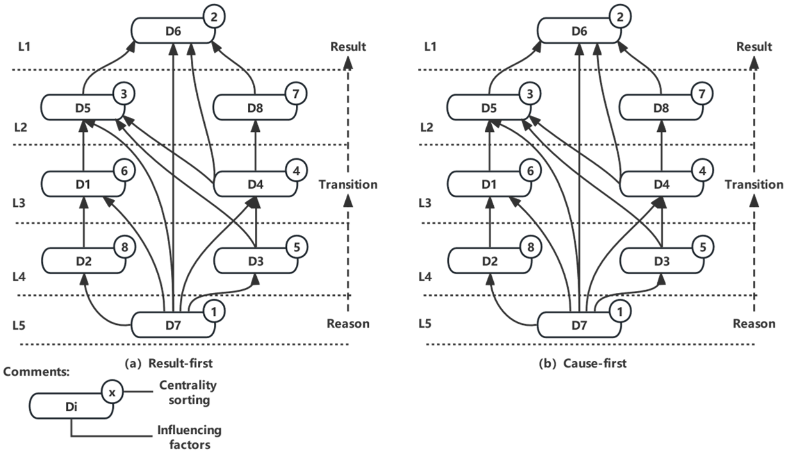

Fig. 4. Confrontation multi-level hierarchical structure model of each factor

5 RESULT ANALYSIS

5.1 Centrality and Cause Degree Analysis

Centrality refers to the importance of an element in the overall system, and the greater the value, the more important the element. It can be seen from Figure 3 that the formulation and implementation of enterprise (D7) and the growth rate of operating profit (D6) are relatively large, indicating that these two factors have relatively important significance in the process of technological innovation of construction enterprises.

Cause degree reflects the degree of influence of one factor on other factors. When the cause degree is greater than 0, it means that the factor has a more significant impact on other factors and is the cause factor. On the contrary, when the cause degree is less than 0, it means that the factor is more affected by other factors. It can be seen from Figure 3 that the formulation and implementation of enterprise (D7), the proportion of personnel with senior professional titles(D3) and the proportion of researchers (D4) are higher, indicating that these factors have more influence on other factors in the system. Therefore, construction enterprises should pay more attention to the influence of these three factors in the process of scientific and technological innovation.

5.2 Key Factors Analysis

The AISM model divides the 8 influencing factors into five layers. Also,there are three levels:the essential level constituted by the lowest level(L5)factor,the transitional level constituted by the middle level(L2-L4) factors,and the proximity level constituted by the uppermost level(L1) factor.

Among them, the direct influencing factor of technological innovation of construction enterprises is the growth rate of operating profit (D6) It is located in the L1 and some other factors affect the whole system by influencing it and then affect the technological innovation of construction enterprises.Choosing the growth rate of operating profit can better measure the profitability of construction enterprises and its momentum and potential.At the same time, the core business of construction enterprises is building and civil engineering, and various adjustments and improvements are ultimately reflected in the growth of profits. Therefore, other factors have an impact on the growth rate of operating profits, which directly affects the scientific and technological innovation of construction enterprises.

The deeper factors impacting the technological innovation of construction enterprises is located in the fifth layer.It is the formulation and implementation of enterprise (D7).It directly or indirectly affects other factors in the system.Only by developing a clear scientific and technological innovation strategy and having sufficient feasibility can construction enterprises achieve stable and sustainable development and be in an invincible position in the fierce market competition. The formulation of scientific and technological innovation strategy is very important for every construction enterprise. A good innovation strategy can help enterprises determine a clear direction, better integrate resources, and find their own advantages in the environment.

The factors in the transitional layer have an impact on the factors in the upper layer. Figure 4 shows that the factors in the transitional layer are the growth rate of research funding (D1), the level of investment in scientific research funds (D2), the proportion of personnel with senior professional titles (D3), the proportion of researchers (D4), patents and awards obtained by enterprises (D5), and leaders' ability to manage innovation (D8). These six factors include four levels, influenced by the essential level,they form a connecting link between the preceding and the following.So it is necessary to control these factors,especially the factors with high centrality.In summary, the factors of the middle layer are mainly reflected in two aspects: funding and talent input.For the scientific and technological innovation of construction enterprises, R&D funds are the source of scientific and technological innovation activities, and have a key impact on the competitiveness of enterprises.On the other hand, talents with professional quality are the driving force of scientific and technological innovation process. Scientific research talents are irreplaceable for the long-term development of enterprises

6 CONCLUSIONS AND RECOMMENDATIONS

The study integrates the DEMATEL-AISM model to evaluate the key influencing factors of the scientific and technological innovation of construction enterprises. The model can provide scientific guidance for the leaders and government and help decision makers to effectively improve the technological innovation process of construction enterprises.Based on the calculation and result analysis,this paper puts forward targeted countermeasures and suggestions for improving the efficiency of technological innovation process in construction enterprises.The suggestions are as follows:

Firstly, the enterprise should formulate the correct science and technology innovation strategy and ensure the implementation of the strategy.Construction enterprises need to conduct sufficient market research and analysis.The enterprise should establish a clear positioning for itself, and by identifying market opportunities and potential areas for innovation, it can determine the direction of its innovation.It is also necessary to clarify the strategic objectives of scientific and technological innovation, and these objectives should be consistent with their own long-term development direction.

Secondly,construction enterprises should pay attention to the input of funds and the introduction and training of talents.The allocation of scientific research funds is aimed not only at short-term gains, but also at ensuring the long-term competitiveness and sustainability of enterprises, as well as providing high-quality,safe,and environmentally friendly construction products and services for society.Enterprises need to attract high-level innovative talents and enhance the scientific research spirit and atmosphere of the team. It is necessary to implement a reasonable talent training plan to help scientific talents get better development.On the other hand, enterprises should strengthen the cooperation with research institutes and universities to implement various forms of scientific innovation cooperation mechanisms.In this way, the innovation collaboration between construction enterprises and scientific research institutions can be accelerated.

Finally, attach importance to organizational management. Organized and purposeful management is also a strong guarantee for enterprises in the process of innovation and development.In the daily management work of construction enterprises, appropriate management concepts and methods can effectively guide and regulate personnel's thoughts and actions,ensure consistency within the organization and help employees of the enterprise to achieve the common development goals.

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