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A study on the cost factors of prefabricated buildings under the Engineering Procurement Construction model based on the interpreted structural model

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ABSTRACT. *In order to promote the transformation of China's construction industry to industrialization and promote the sustainable development of the construction industry. Based on the interpreted structure model, the influence factors of prefabricated building cost are considered in the EPC project general contracting model, and the cost influencing factor structure model of design stage, procurement stage and construction stage is constructed. Under this model, the various factors are interrelated to form a complex system, and the relevant data are from the ISM group composed of relevant experts in the construction industry. Results indicate that the rate of prefabricated, component usage, the output of a file, and inventory management is surface factor affecting the cost, the usage of machinery and equipment, the geographical location of a file, the level of the hoisting installation, field management level and the causes of the rationality of the component split is an intermediary, standar disation of the modulus, the degree of professional design personnel and the special requirements of project owner is the root cause. In order to further reduce the cost of prefabricated buildings, it is necessary to strengthen the skill training of designers and standardize the uniform modulus standards.*

KEYWORDS: *prefabricated building, interpretation of structural models, EPC engineering general contracting, cost*

1. Introduction

In order to promote the transformation and upgrading of China's construction industry, promote the sustainable development of construction industry, construction industry in our country the industrialization, integration and information technology, solve building engineering has been in serious time and overtime charge overweight problem, the State Council successively promulgated a series of policies to promote prefabricated construction comprehensively, the future development of a good situation. With the reform and opening up since the deepening of China's

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urbanization process and the continuous improvement of the level of science and technology, urban construction on the road of industrialization is an inevitable trend. Prefabricated construction in our country with the developed countries such as Europe, America, Japan, in contrast, is still in its infancy stage, immature system make the advantages of prefabricated construction can not be displayed, and there are even more severe than the traditional cast-in-situ construction of extended and overruns phenomenon, which seriously hindered the promotion of prefabricated construction, developers are based on the reason of its own profit, still tend to adopt the traditional cast-in-situ mode of production, how to reduce the cost of prefabricated construction is to make the first condition of its comprehensive development.

Facing the high cost of assembly construction in China, domestic and foreign scholars have done a lot of research on it. Li et al.[1] analyzed the driving factors affecting prefabricated construction cost by establishing an explanation structure model, and showed that the reduction of on-site operation is the fundamental driving factor for component factory production. Zhao et al.[2] used the analytic hierarchy process to consider the influence factors of prefabricated building cost in terms of design, management, technology and policy. Kang et al.[3] analyzed the development efficiency of prefabricated buildings from the five aspects of policy orientation, economy, technology, talent and society, and concluded that the development level of economy and the integrity of the industrial chain of prefabricated buildings had the greatest constraint on the development of prefabricated buildings. Based on the concept of lean cost, Shen et al.[4] analyzed the cost of prefabricated buildings from the aspects of design, production, logistics and installation, and put forward corresponding Suggestions for each stage in order to reduce the cost.Chang et al.[5] used group technology and planning theory in the production stage of prefabricated components (PC) to establish an optimization model for mass production of multiple PCS in groups with the objective function of minimizing PC production cost. With the integration of multiple industries, EPC mode, as a new construction project implementation mode, has been more and more well received by owners and contractors[6]. The extensive application of EPC mode in traditional cast-in-place construction projects has been applied to prefabricated buildings, lifting prefabricated houses to a new height. Jerjeas et al.[7] found out the factors to improve the production of future projects, including project management, prefabrication and pre-construction, by investigating the owners and contractors in EPC projects. Li et al.[8] conducted a highly integrated analysis of BIM, prefabricated building and EPC models, and concluded that under the EPC project general contract management model, the concept of BIM technology collaborative integration and the concept of prefabricated building integration can be highly integrated with more prominent advantages. W. Edward et al.[9] can greatly reduce the cost and schedule of EPC processes by improving internal information exchange and integrating project-based information across organizational boundaries. Nuzul et al.[10] took the four-story school building in Malaysia as an example to compare the cost of traditional construction and assembly method and found that the cost of industrialized building system was significantly lower than that of traditional method. Feng et al. [11] studied the assembly plant cooperation mechanism through evolutionary game theory, believing that the government can support manufacturing enterprises to establish stable partnership through effective punishment and incentive mechanism, reduce the initial cost of the assembly building supply chain, and achieve a win-win situation.

The above scholars have studied the cost of prefabricated buildings from various aspects, but there are few researches on the prefabricated building production under EPC general contracting mode. Therefore, from the perspective of EPC, this paper analyzes the cost influencing factors of prefabricated buildings, and then finds out the most fundamental influencing factors, and carries out targeted Suggestions to promote the long-term development of prefabricated buildings.

2. Prefabricated building cost factors explain the structural model

2.1 Determine the influencing factors of prefabricated construction cost in EPC mode

A prefabricated building is a building assembled by prefabricated components on site, with a construction method of pre-design, factory processing and site installation. The difference between a prefabricated building and a cast-in-place building is that after the components are designed by the design unit, they are directly processed by a prefab factory and shipped to the construction site for installation. The cost generated in this series of processes is affected by many factors, and the factors influencing the cost generated at any stage are all interrelated and inseparable. Therefore, to find out the influencing factors at each stage, relevant measures can be taken to reduce the cost of prefabricated buildings. In the traditional construction management process, design and construction units operate independently and lack of communication between each other, which easily leads to various unexpected problems in the implementation stage and inevitably leads to the increase of costs. In order to overcome the "island of information" phenomenon among the relevant units, the adoption of EPC (engineering general contracting mode), the design, procurement and construction of the three parties into one, can be timely and effective communication and exchange, to avoid the cost waste caused by the delay in the transfer of information. According to the characteristics of the EPC, prefabricated construction costs involved in design, procurement and the major influencing factors of the three aspects of construction, the effect factors of these three aspects to conduct a comprehensive analysis, is the basis of explanation structure model is set up, after the expert group of ratings and discussion, this paper puts forward the EPC mode prefabricated construction cost of the index system of influencing factors, see in Figure 1.

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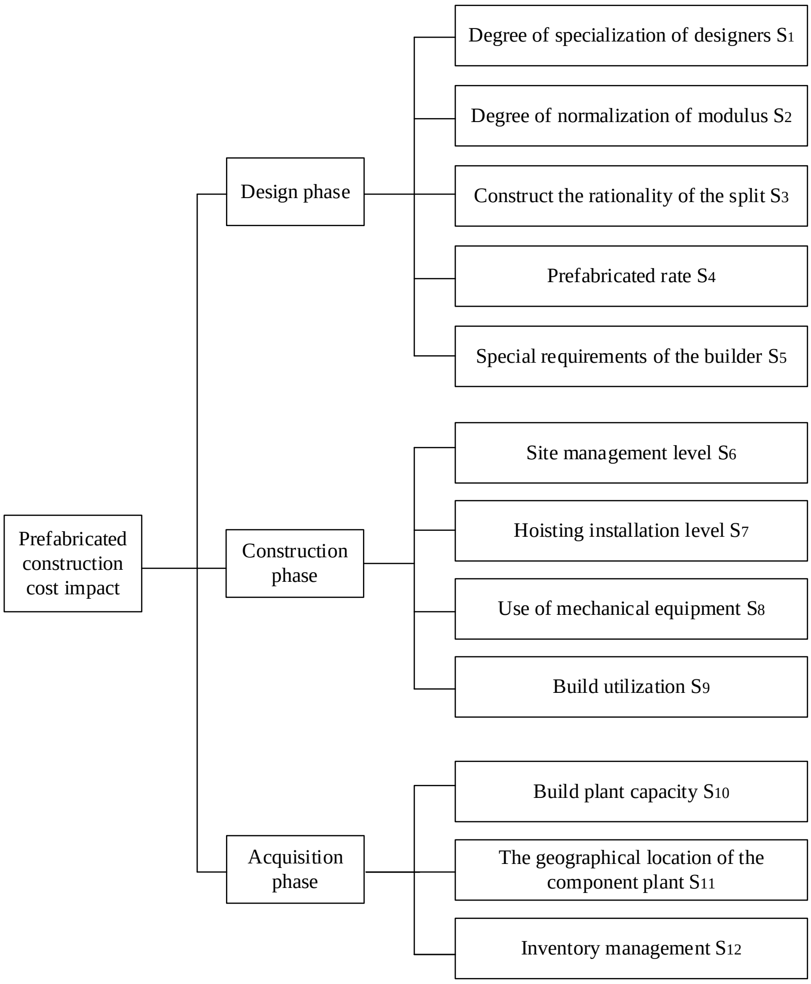

Figure.1 Factors influencing prefabricated construction cost

2.2 Solve the explain structure model

There are many factors influencing the cost of prefabricated buildings, and the factors are interrelated. The different factors that restrict the cost of prefabricated buildings can be regarded as a complex system. Interpretative structure model (ISM) is a static qualitative model proposed by American professor j. huafelt in 1973, which can transform vague ideas into intuitive concrete hierarchical structure model and be applied to complex socio-economic system. Therefore, this paper applies ISM to the cost analysis of prefabricated buildings in EPC mode, and USES ISM to analyze the logical relationship among factors that affect the cost of prefabricated

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buildings. Based on the previous analysis, it is concluded that the factors affecting prefabricated construction cost are shown in table 1.

Table 1 Factors influencing prefabricated construction cost

Classify	Symbol	Influence factor
Design phase	S_1	Degree of specialization of designers
	S_2	Degree of normalization of modulus
	S_3	Construct the rationality of the split
	S_4	Prefabricated rate
	S_5	Special requirements of the builder
Construction phase	S_6	Site management level
	S_7	Hoisting installation level
	S_8	Use of mechanical equipment
	S_9	Build utilization
Acquisition phase	S_{10}	Build plant capacity
	S_{11}	The geographical location of the component plant
	S_{12}	Inventory management

2.2.1 Determine the adjacency matrix

Refer to a large number of relevant literature both at home and abroad, through the way of literature review and group discussion to determine the influence factors of prefabricated construction cost is divided into 12, will design the degree of specialization, standardization of the modulus, the rationality of the component split, prefabricated rate, technological requirements, site management level, hoisting installation, mechanical equipment usage, usage of components, production capacity of a file, file the location and inventory management of these 12 factors were numbered $S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}$.

On this basis, an adjacency matrix of 12 rows and 12 columns is constructed according to the principle of ISM. By convention, all the elements in the adjacency matrix are assumed to be a_{ij}, When factor S_i has an impact on S_j, the corresponding matrix element a_{ij} is 1; when factor S_i has no impact on S_j, the matrix element a_{ij} is 0, that is:

$$a_{ij} = \begin{cases} 1, S_i \ had \ an \ effect \ on \ S_j \\ 0, S_i had \ no \ effect \ on \ S_j \end{cases}$$

As can be seen from the following adjacency matrix, the diagonal elements in the matrix are all 0, while the off-diagonal elements have no rules to follow, which are determined by the discussion group composed of experts in the construction industry. The matrix is as follows:

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$$A=\begin{pmatrix} 0&0&1&0&1&0&0&0&0&0&0&0\\ 0&0&1&0&0&0&1&0&0&0&0&0\\ 0&0&0&0&0&0&1&0&1&0&0&0\\ 0&0&0&0&0&0&0&0&0&0&0&0\\ 1&0&1&0&0&0&0&0&0&0&0&0\\ 0&0&0&0&0&0&1&1&1&0&0&0\\ 0&0&0&0&0&0&0&1&1&0&0&0\\ 0&0&0&0&0&0&0&0&1&0&0&0\\ 0&0&0&0&0&0&0&0&0&1&0&0\\ 0&0&0&1&0&0&0&0&1&0&0&1\\ 0&0&0&0&0&0&0&0&0&0&0&1\\ 0&0&0&0&0&0&0&0&1&0&0&0 \end{pmatrix}$$

2.2.2 Solve the reachable matrix

The adjacency matrix A plus the identity matrix I gives us A new matrix $(A+I)$, According to the Boolean algorithm $(0=0+0, 1=1+0, 1=1+1, 0=0\times 0, 0=0\times 1, 1=1\times 1)$, If the matrix A satisfies $(A+I)^{k-1}\neq(A+I)^{k}=(A+I)^{k+1}$, The new matrix M is the reachable matrix. The adjacency matrix can be solved by programming software MATLAB, and the corresponding reachable matrix M can be obtained when $K=4$.

$$M=\begin{pmatrix} 1&0&1&1&1&0&1&1&1&1&0&1\\ 0&1&1&1&0&0&1&1&1&1&0&1\\ 0&0&1&1&0&0&1&1&1&1&0&1\\ 0&0&0&1&0&0&0&0&0&0&0&0\\ 1&0&1&1&1&0&1&1&1&1&0&1\\ 0&0&0&1&0&1&1&1&1&1&0&1\\ 0&0&0&1&0&0&1&1&1&1&0&1\\ 0&0&0&1&0&0&0&1&1&1&0&1\\ 0&0&0&1&0&0&0&0&1&1&0&1\\ 0&0&0&1&0&0&0&0&1&1&0&1\\ 0&0&0&1&0&0&0&0&1&1&1&1\\ 0&0&0&1&0&0&0&0&1&1&0&1 \end{pmatrix}$$

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2.2.3 Hierarchical decomposition of reachable matrices

The reachable matrix is divided into two parts, namely the reachable set $R(S_i)$ and the antecedent set $Q(S_i)$. The reachable set is determined according to the element whose column value is 1 corresponding to the corresponding row element in the M matrix, and the antecedent set is determ M matrix, and then the intersection is obtained $A = R(S_i) \cap Q(S_i) = R(S_i)$, In this case, intersection A is the biggest influencing factor of the current level. When the maximum influencing factor of this level is determined, the influencing factor is deleted from the set table, and then the reachable set, the antecedent set and their intersection are re-determined according to the new set table, and the new maximum influencing factor is obtained again. This work is repeated until the last influencing factor is obtained. Finally, according to the obtained hierarchical results, the rearrangement of the accessibility matrix is performed to complete the hierarchical processing, as shown in table 2.

Table 2 Relation of reachable set, antecedent set and intersection in reachable matrix

Influence factor S_i	Reachable set $R(S_i)$	First set $Q(S_i)$	Intersection
Degree of specialization of designers	S_1, S_3, S_4, S_5, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_5	S_1, S_5
Degree of normalization of modulus	S_2, S_3, S_4, S_7, S_8、S_9, S_{10}, S_{12}	S_2	S_2
Construct the rationality of the split	S_3, S_4, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5	S_3
Prefabricated rate	S_4	S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}	S_4
Special requirements of the builder	S_1, S_3, S_4, S_5, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_5	S_1、S_5
Site management level	S_4, S_6, S_7, S_8, S_9, S_{10}, S_{12}	S_5	S_5
Hoisting installation level	S_4, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7	S_7
Use of mechanical equipment	S_4、S_8、S_9、S_{10}、S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8	S_8
Build utilization	S_4, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8 S_9, S_{10}, S_{11}, S_{12}	S_9, S_{10}, S_{12}
Build plant capacity	S_4, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}	S_9, S_{10}, S_{12}
The geographical location of the	S_4, S_9, S_{10}, S_{11}, S_{12}	S_{11}	S_{11}

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component plant			
Inventory management	S_4, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}	S_9, S_{10}, S_{12}

It can be known from table 2 that S_4 is the highest influencing factor. After deleting S_4, the highest influencing factor at the next level can be known from the new table 3.

Table 3 Reachable set, antecedent set and their intersection after removing S_4

Influence factor S_i	Reachable set $R(S_i)$	First set $Q(S_i)$	Intersection
Degree of specialization of designers	S_1, S_3, S_5, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_5	S_1, S_5
Degree of normalization of modulus	S_2, S_3, S_7, S_8, S_9, S_{10}, S_{12}	S_2	S_2
Construct the rationality of the split	S_3, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5	S_3
Prefabricated rate	S_1, S_3, S_5, S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_5	S_1, S_5
Special requirements of the builder	S_6, S_7, S_8, S_9, S_{10}, S_{12}	S_5	S_5
Site management level	S_7, S_8, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S5, S_6, S_7	S_7
Hoisting installation level	S_8, S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8	S_8
Use of mechanical equipment	S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8 S_9, S_{10}, S_{11}, S_{12}	S_9, S_{10}, S_{12}
Build utilization	S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}	S_9, S_{10}, S_{12}
Build plant capacity	S_9, S_{10}, S_{11}, S_{12}	S_{11}	S_{11}
The geographical location of the component plant	S_9, S_{10}, S_{12}	S_1, S_2, S_3, S_5, S_6, S_7, S_8 S_9, S_{10}, S_{11}, S_{12}	S_9, S_{10}, S_{12}

It can be seen from table 3 that S_9, S_{10} and S_{12} are the factors with the highest influence. After the three factors of S_9, S_{10} and S_{12} are deleted, the highest influence factors at the next level can be known according to the newly obtained table 4.

Table 4 The reachable set, antecedent set and their intersection after removing S_9, S_{10} and S_{12}

Influence factor S_i	Reachable set $R(S_i)$	First set $Q(S_i)$	Intersection

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Degree of specialization of designers	S_1, S_3, S_5, S_7, S_8	S_1, S_5	S_1, S_5
Degree of normalization of modulus	S_2, S_3, S_7, S_8	S_2	S_2
Construct the rationality of the split	S_3, S_7, S_8	S_1, S_2, S_3, S_5	S_3
Special requirements of the builder	S_1, S_3, S_5, S_7, S_8	S_1, S_5	S_1, S_5
Site management level	S_6, S_7, S_8	S_6	S_6
Hoisting installation level	S_7, S_8	S_1, S_2, S_3, S_5, S_6, S_7	S_7
Use of mechanical equipment	S_8	S_1, S_2, S_3, S_5, S_6, S_7, S_8	S_8
The geographical location of the component plant	S_{11}	S_{11}	S_{11}

It can be seen from table 4 that S_8 and S_{11} are the factors with the highest influence. After removing these two factors, the highest influence factors at the next level can be known according to the newly obtained table 5.

Table 5 The reachable set, antecedent set and their intersection after S_8 and S_{11} are excluded

Influence factor S_i	Reachable set $R(S_i)$	First set $Q(S_i)$	Intersection
Degree of specialization of designers	S_1, S_3, S_5, S_7	S_1, S_5	S_1, S_5
Degree of normalization of modulus	S_2, S_3, S_7	S_2	S_2
Construct the rationality of the split	S_3, S_7	S_1, S_2, S_3, S_5	S_3
Special requirements of the builder	S_1, S_3, S_5, S_7	S_1, S_5	S_1, S_5
Site management level	S_6, S_7	S_6	S_6
Hoisting installation level	S_7	S_1, S_2, S_3, S_5, S_6, S_7	S_7

It can be seen from table 5 that S_7 is the factor with the highest influence. After deleting S_7, the highest influence factors at the next level can be known according to the newly obtained table 6.

Table 6 Reachable set, antecedent set and their intersection after removing S_7

Influence factor S_i	Reachable set $R(S_i)$	First set $Q(S_i)$	Intersection
Degree of specialization of designers	S_1, S_3, S_5	S_1, S_5	S_1, S_5
Degree of normalization of	S_2, S_3	S_2	S_2

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modulus			
Construct the rationality of the split	S_3	S_1, S_2, S_3, S_5	S_3
Special requirements of the builder	S_1, S_3, S_5	S_1, S_5	S_1, S_5
Site management level	S_6	S_6	S_6

It can be seen from table 6 that the two factors S_3 and S_6 are the factors with the highest influence. After removing the two factors S_3 and S_6, the highest influence factors at the next level can be known according to the newly obtained table 7.

Table 7 The reachable set, antecedent set and their intersection after S3 and S6 are excluded

Influence factor S_i	Reachable set $R(S_i)$	First set $Q(S_i)$	Intersection
Degree of specialization of designers	S_1, S_5	S_1, S_5	S_1, S_5
Degree of normalization of modulus	S_2	S_2	S_2
Special requirements of the builder	S_1, S_5	S_1, S_5	S_1, S_5

It can be seen from table 7 that S_1, S_2 and S_5 are the highest influencing factors.

2.3 Establishment of interpretative structure model

It can be seen from the division of accessibility matrix that the structural model of prefabricated building cost influencing factors in EPC mode is divided into 6 levels. Firstly, the hierarchical relationship among different levels is divided, and then the structure model is obtained. The model is shown in figure 2 below:

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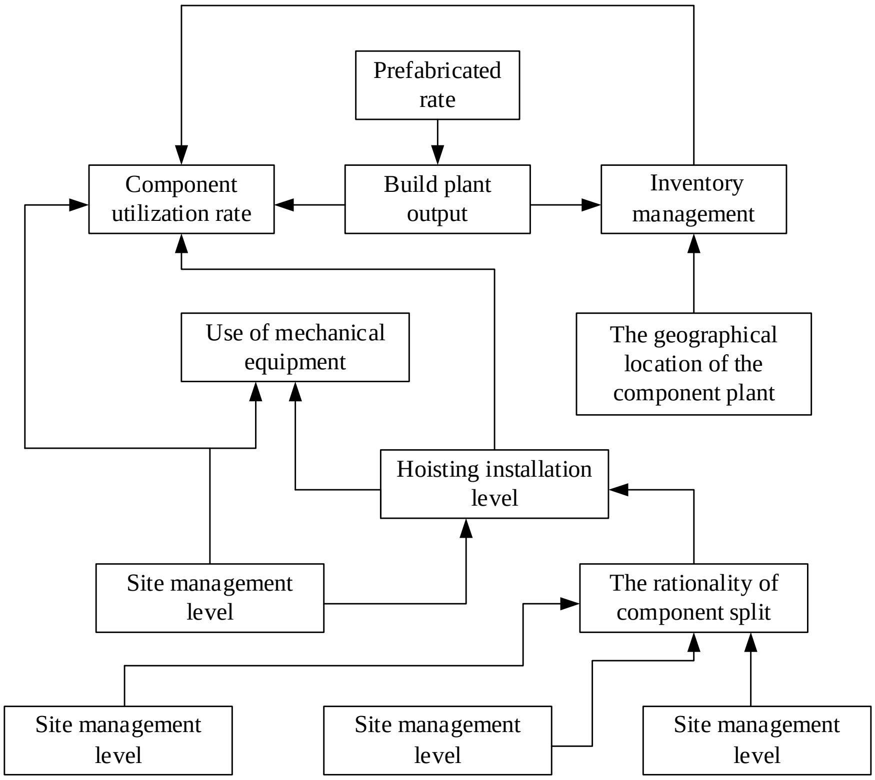

Figure. 2 Illustrates the structure model

3 Result analysis

As can be seen from the above structure diagram, the factors influencing the cost of prefabricated building are a complex system divided into six levels. All the factors within the system are interrelated and interact with each other. According to the actual situation that affects the cost of prefabricated building, the hierarchical structure diagram is analyzed:

(1) The superficial factors that affect prefabricated construction cost are the first and second layers, including prefabrication rate, component utilization rate, component plant output and inventory management. It means that these four factors can directly affect the cost of prefabricated buildings, and are the direct cause of determining the cost of prefabricated buildings. In order to reduce the cost of prefabricated buildings, we must pay attention to these four factors.

(2) The factors that affect prefabricated building cost are the third, fourth and fifth layers, including the use of mechanical equipment, the geographical location of the component plant, the level of hoisting and installation, the level of site

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management and the rationality of component separation, indicating that these five factors indirectly affect the cost of prefabricated building. The use of mechanical equipment on the construction site will affect the operation level of hoisting and installation of technical workers. When the improper use of equipment leads to the failure of installation of workers, the depreciation of equipment will affect the cost of prefabricated buildings. The level of site management affects the use of machinery and equipment, thus affecting the cost of prefabricated buildings; The rationality of site management level and component separation affects the use of mechanical equipment by influencing the level of hoisting and installation, thus affecting the cost of prefabricated buildings.

(3) The deep reasons that affect the prefabricated building cost are the standardization degree of design, the specialization degree of designers and the special requirements of constructors. In the future construction process, the international module standards should be established to strengthen the professional skills of designers, so as to meet the special requirements of construction parties to the greatest extent, so as to effectively unify the market of prefabricated buildings and thus reduce the cost of prefabricated buildings.

4. Suggestions and measures

Through the analysis of the established interpretive structure model, it can be seen that no matter the surface reason, the middle reason or the deep reason, all have a deep impact on the cost of prefabricated building.

(1) Standard module, in line with international standards.

The design of prefabricated buildings is different from the previous cast-in-place concrete buildings, and there is no reference specification and unified technical standard system, which leads to the component sizes produced by different construction plants being quite different, which is difficult to meet the market demand. Therefore, the standard of uniform and standard module can make the production mold of components be used repeatedly. Although the one-time input cost of large quantities of production components is large, it can reduce the production input cost for a long time.

(2) Appropriate site selection of component plant

Prefabricated in the factory production is completed, will be stored in the factory warehouse, and then by the means of transport to the construction site, transportation distance and the key factors is to determine the cost of transportation, will set up a file in the near 100 km from the construction site and material supply, greatly improve the speed of material supply, reducing the shutdown caused by the lack of raw materials cost, also can send components to the scene in a shorter time, and reduce the cost of inventory management.

(3) Training of professional production and installation workers.

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At present, because the prefabricated building is in its infancy, there is no domestic first-class production and installation workers. In the production stage, due to technical limitations. As a result, many components produced cannot be used in actual construction, resulting in waste of raw materials and damage of equipment. In the construction process, the lack of technology and experience of the installers will easily lead to the damage of the components during the assembly. With each use of the mechanical equipment, the service life of the equipment will be correspondingly reduced and the maintenance cost will be correspondingly increased. So training workers technical level is imminent, although in the short term workers training investment is big, but from a long-term point of view, the worker of skilled technology will save a lot of cost in terms of raw materials and finished products, and production and construction of a one-time successful, reduce use frequency and the wear of mechanical equipment, equipment maintenance.

5. Conclusion

Prefabricated buildings are in full fire, and the country has also introduced many incentive policies to encourage enterprises to adopt prefabricated buildings, such as cost subsidy. When the assembly rate reaches a certain proportion, a certain amount of cost price per square meter will be subsidized accordingly. This will greatly encourage companies to adopt prefabricated buildings. Prefabricated buildings can not only solve the long-term problems of construction period overruns and cost overruns, but also conform to the national concept of "four sections and one environmental protection". The development of prefabricated buildings is an important step in the transformation of China's construction industry to industrialization. However, at present, the promotion of prefabricated buildings is not accepted by most enterprises due to its large cost input. Therefore, reducing the input cost of prefabricated buildings is an important reason for its great development. Through a series of means, such as the training of workers' technical level, the selection of component factories in appropriate geographical locations and modulus coordination, the cost of prefabricated buildings will be effectively reduced and a solid foundation will be laid for the vigorous development of prefabricated buildings.

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