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Research on Material Quality Risk Management Based on Machine Learning for Prefabricated Civil Buildings

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Abstract:

Forming the quality of prefabricated components of prefabricated buildings runs through multiple links of design, production, transportation, and assembly, and multiple links are linked to form a quality chain. This paper sorts out the production and technological processes of prefabricated components of prefabricated buildings. According to the construction process requirements of prefabricated buildings, the construction quality evaluation of prefabricated buildings is divided into dimensions, and an evaluation index system is initially established. In this paper, the rough set theory is used to reduce the indicators, and the weights are established through the analysis of the importance of the indicators. Finally, the countermeasures and suggestions for promoting the development of prefabricated buildings are given. The research results have specific theoretical and practical significance for improving the quality and safety of prefabricated components and promoting the industrialization of construction.

Keywords: *Prefabricated; Civil Construction; Machine Learning; Material Quality Risk Management.*

I. INTRODUCTION

Construction industrialization is the process of constructing construction products in an industrialized production method to improve production efficiency and reduce construction costs. Paper Drawing on the production model of industrial products, Western countries took the lead in proposing the concept of building industrialization. The rapid development of China's society and economy, the great demand for construction products, the rising labor costs, and the requirements for sustainable development have created an environment for China to implement construction industrialization. China is vigorously promoting the industrialized construction production mode [1]. The assembly and construction of prefabricated components to form construction products can reduce labor and improve efficiency and save resources and construction costs and reduce pollution. However, compared with building products in the traditional model, the quality and safety of prefabricated buildings are questioned, and the quality and safety of prefabricated components is the primary factor affecting the overall safety of prefabricated buildings. Therefore, it is indispensable to study the factors affecting the quality and safety of prefabricated components.

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However, the development of prefabricated buildings in China is still low, and a series of complex factors restrict the promotion of prefabricated buildings in China. What factors are restricting its development? Some domestic scholars have carried out relevant research. Some scholars have analyzed the forms faced by prefabricated buildings in Shenyang from the aspects of technology, materials, production processes, policies, and regulations and finally determined the main constraints. Some scholars have analyzed the constraints on developing prefabricated buildings from four aspects: cost, technology, policy, and market. Some scholars have used the PEST analysis method to comprehensively analyze the restrictive factors of the development of China's prefabricated buildings from the perspectives of economy, politics, society, and technology and put forward macroscopic countermeasures and suggestions [2]. These studies have achieved valuable results, but related research needs to be carried out extensively and continuously. The construction quality evaluation method of traditional cast-in-place structures cannot be directly applied to prefabricated buildings due to changes in procedures and content; therefore, this paper develops a systematic and comprehensive construction quality evaluation system for prefabricated buildings: research and analysis.

II. PROCESS ANALYSIS OF THE PRODUCTION STAGE OF PREFABRICATED COMPONENTS

2.1. Production process of prefabricated components

Compared with traditional construction projects, prefabricated buildings mainly increase the process of component design, component factory prefabrication and component on-site hoisting [3]. The work relationship between the component production stage, design and construction stage and construction assembly stage is shown in Figure 1 (picture Referenced in Exploring the Client–AEC Interface in Building Lifecycle Integration).

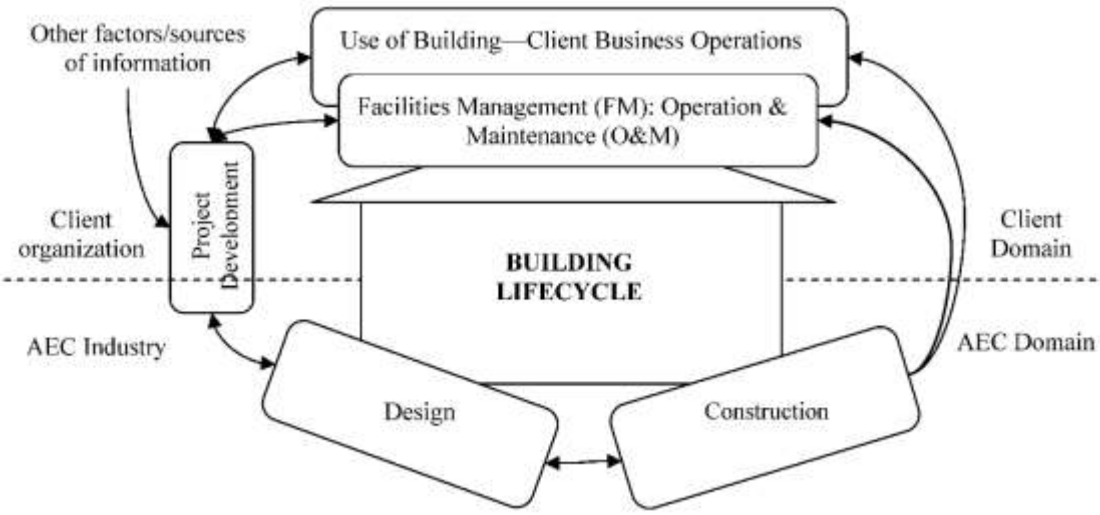

Fig.1 Interaction diagram of component production, design and construction stages

2.1.1 Detailed design of prefabricated components

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In order to make the production-related information contained in the component model more effectively used in the component production process, the detailed design of prefabricated components of prefabricated buildings at this stage is usually carried out with the factory as the main body. On the basis of the component drawings formed by the design institute, combined with the actual production process of the factory, using BIM three-dimensional modeling technology for detailed design [4]. On the basis of satisfying the structural mechanics design, the detailed design of components is based on the multi-professional architectural requirements, combined with the requirements of the factory's own component production process and the needs of the construction and hoisting process, to carry out a detailed design of the geometric dimensions of the components and various embedded parts.

2.1.2 Production management of prefabricated components

The production management of prefabricated components mainly includes: component production planning, the management of people, materials, and machines in the component production process, and component production process control. The component production plan is mainly based on the actual production capacity of the factory and the construction progress requirements of the components of the construction project, to formulate a scientific and effective production schedule. According to the component production plan, manage the labor, materials, machinery, etc. required for component production, and then control the component production process, and adjust the problems that occur in the component production process in time. In order to realize the effective management of component production, the information management platform is gradually applied to the process of component production management [5]. Some scholars use BIM technology to design a production management system for prefabricated components, and improve the quality level and production efficiency of prefabricated components through the support of BIM data. Secondly, for the research on the tracking process of the production information of prefabricated components, some scholars embed radio frequency identification technology tags into the prefabricated components, and combine mobile devices, Internet and database technologies to realize functions such as information collection, data transmission and sharing, and complete the production of components. Process tracking and quick alerts.

2.1.3 Inspection and repair of prefabricated components

Aiming at the quality inspection of the components after the production of the components, it is theoretically proposed to use the laser scanning technology to scan the finished components of the components to form a three-dimensional model for comparison with the design model, so as to judge the production quality of the components. However, at this stage, component factories still use manual inspection methods for quality inspection.

2.2. Production process of prefabricated components

The production process of prefabricated components usually includes the stages of mold cleaning, mold assembly, mold release agent coating, tie-in steel skeleton, installation of embedded parts, concrete

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pouring and vibrating, roughening, steam curing, mold removal, inspection and repair, and stacking. The production process for specific components will be adjusted according to the component type and the production capacity of the component factory [6]. At present, the research focus on component production technology at home and abroad mainly focuses on realizing component production automation and improving component production efficiency. The prefabricated component production equipment in developed countries such as the United States, Japan and Germany has gradually entered the high automatic level of overall coordination from the automation of a separate process link, and the component production equipment has a high level of integration and mechanization. The domestic automated production line started relatively late, and at this stage, it can only automate individual process links. The main applications of automated processes include automatic layout and removal of molds, automatic spraying of mold release agents, reinforced mesh processing, concrete pouring and vibrating, automatic For individual aspects such as steam curing and automatic wall overturning, manual assistance is still required to complete the production of components in the entire production process. Figure 2 can more intuitively show the production stage and automation level of each production process of prefabricated components in China at this stage (the picture is quoted from Cost Analysis of Prefabricated Elements of the Ordinary and Lightweight Concrete Walls in Residential Construction).

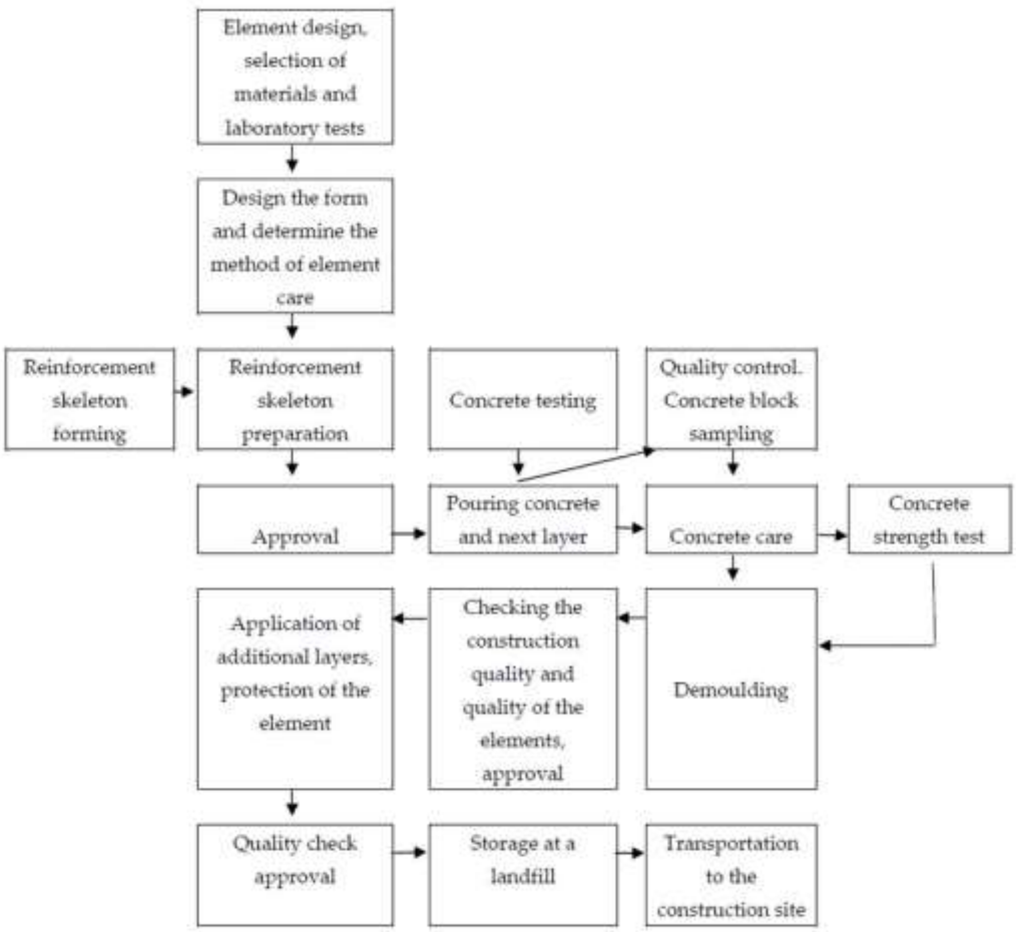

Fig.2 Production process flow of prefabricated components

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Among them, there are differences in the actual production of various components due to the differences in shape, pre-embedded and force of different types of components. Prefabricated components usually include prefabricated columns, prestressed composite beams, ordinary composite beams, prestressed composite panels, prestressed hollow panels, prefabricated shear walls, prefabricated partition panels, prefabricated external panels, prefabricated air conditioning panels, prefabricated balconies, prefabricated Bay windows, prefabricated stairs and other modeling components. Taking the prestressed laminated plate as an example, the prestressed tendon tensioning process is increased compared with the ordinary laminated plate.

III. CHARACTERIZATION OF FACTORS AFFECTING THE QUALITY OF PREFABRICATED COMPONENTS

Compared with traditional cast-in-place structures and product quality requirements in manufacturing, the quality requirements of prefabricated components are higher. Prefabricated components are the key carrier of multi-dimensional work space quality and safety risk transmission of prefabricated construction projects, and are also important components that affect the quality and safety of prefabricated building structures. The core of quality chain control of prefabricated building components is total quality management and whole process control [7]. By visiting and investigating 9 prefabricated component factories in W city, and summarizing and analyzing the relevant literature on the quality of prefabricated buildings, considering the influence of personnel, equipment, materials, technology, management and environment on the quality of prefabricated components, combined with prefabricated components From the design, production, transportation and assembly of quality generation, the matrix of factors affecting the quality of the whole process of prefabricated building components is obtained.

3.1. Personnel

Personnel in the design, production, transportation and assembly stages are the decision-makers, managers and implementers of the quality of prefabricated components, and their professional abilities and work activities will directly or indirectly affect the quality of prefabricated components. Therefore, the human factor is the key factor that leads to the quality problems of prefabricated components.

3.2.2. Equipment

The stability of the operation of the production equipment and the quality of the mold assembly will directly affect the function of the prefabricated components. Considering the specifications of the prefabricated components, select transportation vehicles, on-site hoisting machinery, sleeve grouting and other equipment. The performance of the equipment directly determines the installation progress and construction quality of the prefabricated components.

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3.2.3. Materials

Prefabricated components are important materials that constitute the entity of a prefabricated building project. The production quality of prefabricated components is directly affected by the quality of its raw materials and the inspection of indicators [8]. The degree of damage to the prefabricated components during transportation and assembly will affect the prefabricated components themselves and thus the quality of the project.

3.2.4. Technology

At present, prefabricated buildings are developing rapidly in China, but there are still technical problems in the design, production, transportation and assembly of prefabricated components that need to be solved urgently [9]. The rationality of the detailed design of prefabricated components, the correct reservation in the production process of prefabricated components, the dimensional accuracy of prefabricated components, the level of process production, the stability of component placement during transportation and assembly, and the integration of electromechanical pipelines directly determine the quality of prefabricated components.

3.2.5. Management

The production process of prefabricated components is different from general products, and its integration, fluidity and coordination characteristics make quality management activities run through the entire production process [10]. According to the characteristics of prefabricated buildings, combined with the requirements of quality management, consider the pre-production preparation and inspection of prefabricated components, transportation preparation and planning, on-site storage and protection of prefabricated components, hoisting plans and positioning, combined with information technology, pre-production and overall planning of component production, Transportation, assembly and various professional needs ensure the integration of design drawings.

3.2.6. Environment

Environmental factors include management environment, operating environment and natural environment. Considering the prefabrication and integration of prefabricated buildings, the coordination and cooperation of various disciplines are required to produce a good management environment in the design stage. The temperature and humidity of the prefabricated component production workshop, policies during transportation and road restrictions in the factory area, the assembly site environment, and natural disasters will all have an impact on the quality of prefabricated components.

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IV. INDEX OPTIMIZATION OF EVALUATION SYSTEM BASED ON ROUGH SET

4.1. The principle of index selection based on rough sets

Starting from the principle of purpose, the indicators are mainly based on the evaluation purpose, and on a scientific and reasonable basis, select objective factors that can objectively reflect the construction quality of the evaluation object. Starting from the principle of comprehensiveness, the selection of indicators should be as comprehensive and representative as possible, covering all aspects of prefabricated buildings, and the indicators should be as relevant, hierarchical and comprehensive as possible. Starting from the principle of comparability, the set indicators should be based on the absolute level and relative level, and meet the principle of comparability, that is, the data source, calculation caliber, and calculation method should be as consistent as possible to increase their comparability. Starting from the principle of combinability, the design of the index system should organically combine quantitative analysis with qualitative analysis [11]. On the basis of qualitative analysis, through quantitative processing, the quality information of prefabricated buildings can be accurately reflected. Starting from the principle of operability, the selection of indicators and data sources should use data released by authoritative departments as much as possible to ensure the scientific, authoritative and reliable selection of indicators, thereby ensuring the operability of indicator settings.

4.2. Simplified construction quality evaluation system of prefabricated buildings

Rough set theory is to describe and deal with incomplete information. It can reduce data on the premise of preserving key information, find the minimum expression of knowledge, and show potential laws. Based on rough set theory, this paper makes a parsimonious analysis of the initially set quality evaluation indicators, eliminates the indicators that have little impact on the evaluation system, obtains the main indicators of quality evaluation, builds an evaluation model, and calculates the importance of indicators through rough set theory [12]. The weights are established to evaluate the construction quality.

Let P be the equivalence relation family of the primary selection indicators of prefabricated building quality evaluation, let $Q \subseteq P$, if Q is independent, and Ind(Q)=Ind(P), then Q is called the equivalence relation family P of the primary selection indicators A reduction of , denoted as Red(P). The set of primary selection indicators of all irreducible relations in P is called the core of the equivalence relation family P, denoted as Core(P). The relationship between the index system reduction and the kernel is: the intersection of the reduction set Red(P) is equal to the kernel of P, that is,

$$Core(P) = \bigcap Red(P) \tag{1}$$

Define S=(U, R, V, f) as the index information system of the prefabricated building evaluation system, where: $U = \{x_1, x_2, x_3 ..., x_n\}$ is the domain of the prefabricated building evaluation system, which is the collection of all samples; R is the prefabricated building evaluation system The property set of ,

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namely $R=\{a_1,a_2,a_3...,a_n\}$. R can be divided into condition attribute set $C=\{a_i | i=1,2,...,m\}$ and decision attribute set D={d} reflecting the characteristics of the prefabricated building evaluation system, and $C \cup D = R, C \cap D = \varnothing$. The separate matrix that defines the system is $M(S)=[m_{ij}]_{n\times m}$, and its elements at row i and column j are:

$$m_{ij}=\begin{cases} a_k \in C, a_k(x_i) \neq a_k(x_j) \wedge D(x_i) \neq D(x_j) \\ \varnothing, D(x_i)=D(x_j), i,j=1,2,3,...,n \end{cases} \tag{2}$$

Element m_{ij} in the discrimination matrix is a set of all attributes that can be used to discriminate object x_i, x_j; but if x_i, x_j belongs to the same decision class, the value of element m_{ij} in the discrimination matrix should be an empty set. For each resolution matrix M(S) corresponds to a unique resolution function $f_{M(S)}$. It is the sum of $\vee(m_{ij})$, and $\vee(m_{ij})$ is the disjunction of the elements in the matrix item m_{ij}, that is

$$f_{M(S)}(a_{1\infty},a_2,...,a_m)=\wedge\vee(m_{ij},1\leq j\leq i\leq n, m_{ij}\neq\varnothing) \tag{3}$$

Each conjunction in the disjunctive normal form of the discrimination function corresponds to a reduction, and the kernel is the set of all individual elements in the discrimination matrix, namely

$$Core(R)=\{a_k \in \Re; m_{ij}=\{a_k\}, 1\leq j\leq i\leq n\} \tag{4}$$

V. EMPIRICAL ANALYSIS

The weight of the quality risk index of prefabricated components is determined based on expert scoring, and the 9-level gradient method is used to give the importance value of one index compared to another index to construct a judgment matrix. The eigenvectors of the judgment matrix composed of the influencing factors in the quality risk are (0.2203, 0.0318, 0.3995, 0.0646, 0.1489, 0.1350), among which, the consistency index CR=0.088＜0.1, which is in line with the consistency test. The eigenvectors of the judgment matrix composed of the influencing factors in management risk A are (0.2244, 0.0745, 0.1529, 0.4378, 0.0415, 0.0688), among which, the consistency index CR= 0.050<0.1, which is in line with the consistency test. The eigenvectors of the judgment matrix composed of the influencing factors in environmental risk B are (0.3333, 0.6667), among which, the consistency index CR=0<0.1, which conforms to the consistency test. The eigenvectors of the judgment matrix composed of the influencing factors in the technical risk C are (0.6370, 0.2583, 0.1047), among which, the

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consistency index CR=0.033<0.1, which is consistent with the consistency test. The eigenvectors of the judgment matrix composed of the influencing factors in the material equipment risk D are (0.3333, 0.6667), among which, the consistency index CR=0<0.1, which is in line with the consistency test. The eigenvectors of the judgment matrix composed of the influencing factors in the market risk F are (0.5067, 0.0607, 0.3004, 0.1322), among which, the consistency index CR=0.087<0.1, which is in line with the consistency test. After the consistency index inspection is completed, the quality risk network structure model of prefabricated components is established with the help of Super Decisions software, as shown in Figure 3 (the picture is quoted in Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation).

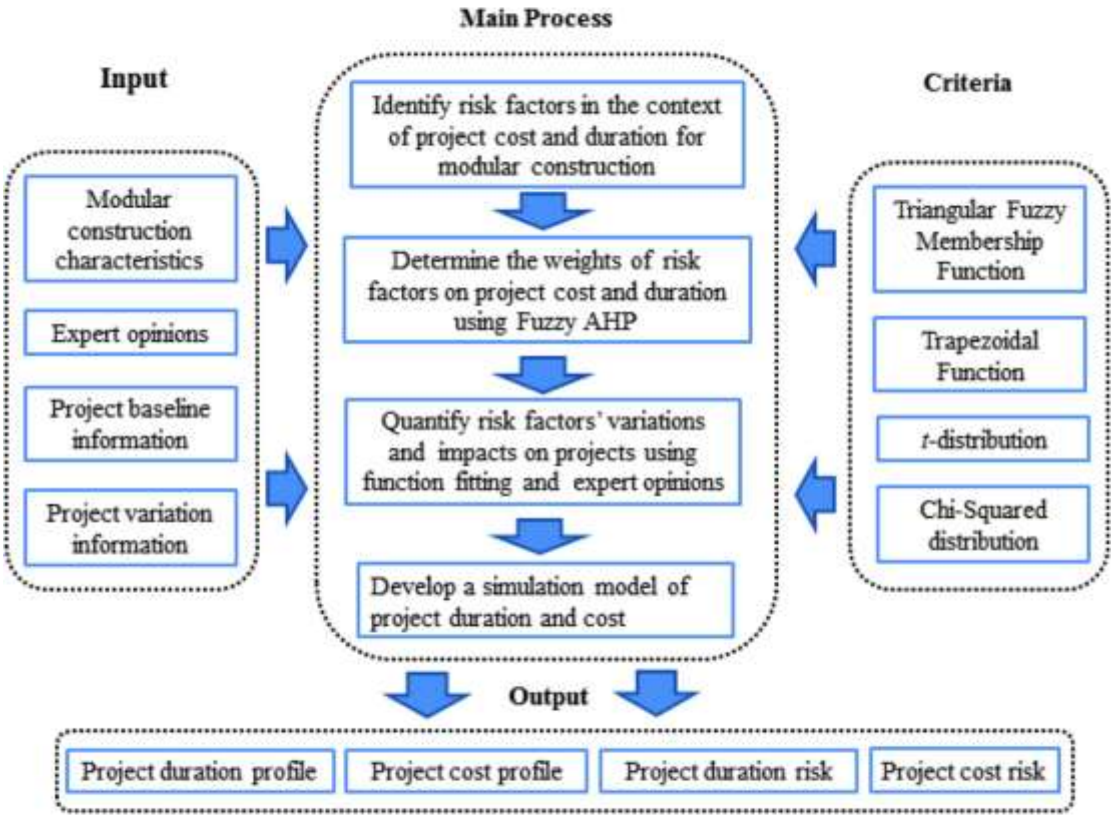

Fig.3 Quality risk network structure model of prefabricated prefabricated components

The ANP supermatrix W, the weighted supermatrix W- and the limit matrix W∞ of the quality risk indicators of prefabricated components are generated by using the Super Decision software, and the weights of the relevant indicators are obtained. According to the actual situation of the prefabricated building project, the G1 method is used to determine that the weight of the contribution of the designer is 0.372, the weight of the contribution of the assembler is 0.266, the weight of the contribution of the production staff is 0.205, and the weight of the contribution of the transportation company is 0.157. Using Vensim software to analyze the change process of the four factors in the system over time is shown in Figure 4 (the picture is quoted in Product Segmentation and Sustainability in Customized Assembly with Respect to the Basic Elements of Industry 4.0).

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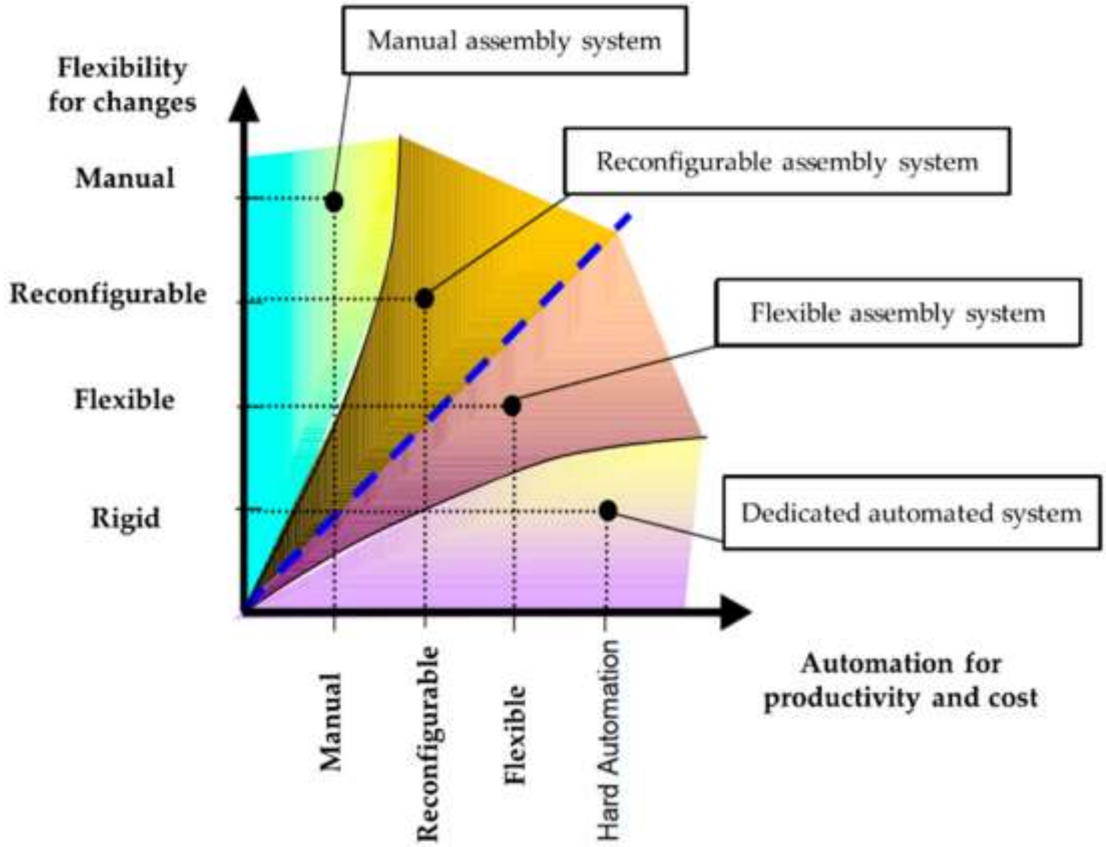

Fig.4 Contribution curves of design, assembly, production, and transportation personnel

It can be seen from Figure 4 that the designer's contribution is the largest in the early stage of the project, and gradually decreases with time; the assembler's contribution is the largest in the on-site assembly stage; the production staff's contribution gradually increases at the end of the design stage; the transport staff's contribution to the production of prefabricated components Gradually rise. The evolution law of the designer's contribution, the assembler's contribution, the production's contribution and the contribution of the transportation company over time is consistent with the actual evolution of the sample project, which verifies the objectivity and validity of the model. , this model considers the impact of prefabricated component quality chain control on project progress. On the basis of empirical simulation, to ensure that the contribution of other personnel remains unchanged, the simulation is carried out to increase the contribution of design, production, transportation and assembly personnel by 40%, and to observe the change of the "schedule pressure" factor through single-factor changes, so as to further optimize Quality chain management scheme for prefabricated components. The running result is shown in Figure 5.

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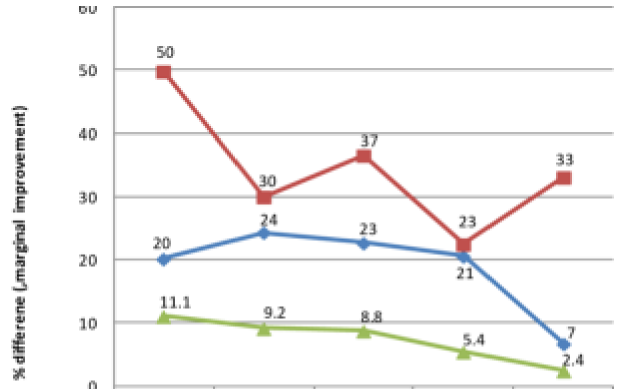

	Houses	Community	Commercial	Apartment	Educational
% Cost saving (19% avg)	20	24	23	21	7
% Time saving (34% avg)	50	30	37	23	33
% Productivity Improvement (7% avg)	11.1	9.2	8.8	5.4	2.4

Fig. 5 Progress pressure curve of prefabricated building after single factor change

It can be seen from Figure 5 that when the contribution of each factor increases by 40%, the change range from large to small is: design, assembly, production, and transportation. Considering the prefabricated buildings, increasing the investment in the design of prefabricated components can coordinate the task requirements of subsequent production, transportation, and assembly in the early stage of the project. Therefore, the design factors change significantly and the construction period is significantly shortened; the assembly construction site is all in the early stage. The integration of work and the increase of investment in the assembly link can be fed back to the design link in the system, thereby shortening the project schedule; changes in production factors promote the progress of the production link of prefabricated components to be greatly advanced, but due to resource constraints in the transportation and assembly links, the range of changes in the later stage of the project Smaller; in the original scheme, the weight of the transportation link is the lowest, and it is restricted by the design, production and assembly of prefabricated components, so the change is not significant compared with the original scheme.

VI. COUNTERMEASURES AND SUGGESTIONS

6.1. Improve the technical system

According to the survey and analysis results, a series of problems in the technical system are the primary reasons for restricting the development of prefabricated buildings. It is recommended to improve and perfect the following aspects: further improve the modular system and modular system, and promote modular coordination; strengthen standardization and The integrated design, combined with the current market demand and product positioning, establishes a standardized component library of prefabricated components to form a standardized management effect; the current prefabricated building structure system design is carried out in accordance with the "equivalent cast-in-place" theory, and there is no introduction based on the characteristics of prefabricated buildings. This phenomenon needs to be

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changed urgently; speed up the establishment of a sound supporting standard and technical system to create a complete industrial chain of prefabricated buildings; strictly control the production quality and splicing and installation quality of components and parts to ensure the overall construction quality and safety.

6.2. Improve the market environment

There is not enough synergy among multiple departments such as prefabricated building design, component production, transportation, construction, and logistics support, and there is also a lack of a clear leading unit and a complete information coordination system. Communication barriers and improve information collaboration efficiency. First of all, the contractor should fully understand and attach great importance to the difference between the management concept adapted to this new construction model and the traditional construction management concept, actively participate in relevant training and learn the management experience of prefabricated building construction from domestic and foreign counterparts, so as to improve the management level. The government and enterprises should vigorously publicize the advantages of prefabricated buildings, so that the public can gradually reduce their dependence on traditional cast-in-place operations, and improve the recognition and support for prefabricated buildings.

6.3. Upgrading the Industrial Organization System

Manufacturers need to enrich the types of prefabricated components to meet the different needs of consumers, and seek progress in the diversity of products, so that users can choose suitable building products according to their own preferences. The prefabricated construction industry chain can be divided into three major links: supply, production and sales services. China's prefabricated buildings are still in the early stage of development, and the imperfect industrial chain is an important factor hindering the development of China's prefabricated buildings. It is difficult for related enterprises to integrate together, so that they cannot jointly exert scale effects. Attention should be paid to optimizing the industrial chain of prefabricated buildings, integrating upstream and downstream enterprises to form a complete industrial chain, realizing the integration of prefabricated buildings from design, production, construction, post-operation and maintenance, and improving the production efficiency of prefabricated buildings. effectiveness.

6.4. Reduce construction costs

The cost of prefabricated buildings is mainly composed of design costs, process costs, tax costs, logistics costs, personnel training costs and equipment costs. Since the development of prefabricated buildings in China is not yet mature, many domestic manufacturers are currently in cost control. It has not been done enough, resulting in the cost of prefabricated construction has been at a high level. We should learn from advanced experience at home and abroad to enhance the cost control ability of prefabricated parts manufacturers, such as improving the specialization degree of production enterprises

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and the standardization degree of components, and improving the large-scale production capacity of enterprises.

6.5. Improve the government's macro-control and support policies

The government should give full play to its management functions and economic functions in the prefabricated construction industry, such as formulating and promulgating corresponding prefabricated building publicity policies to improve the understanding of various construction units and the general public of prefabricated buildings; responsible for the evaluation of various pilot projects Functions related to prefabricated buildings such as evaluation, new process demonstration, parts demonstration, residential performance certification, promote cooperation and exchanges between Chinese enterprises and foreign manufacturers with advanced technology, and learn advanced technology; guide various research institutes and research institutes to develop Research on the production technology of prefabricated buildings, and strive to shorten the gap between China and developed countries in this field. Government departments should also strengthen capital investment in prefabricated buildings. At present, the construction price of prefabricated houses has no advantage over traditional cast-in-place buildings, and a lot of capital investment is needed to promote the development of prefabricated buildings.

6.6. Pay attention to the cultivation of professional talents

Prefabricated buildings are different from traditional buildings and require a large number of professional talents. In the process of promoting prefabricated buildings, the problem of talents is the key to bear the brunt. As the primary factor restricting the development of prefabricated buildings, the core of technical factors lies in the lack of talents. There is still a huge gap in the professional talents required for the industrialization of construction. Therefore, cultivating professional talents that meet the development needs of the prefabricated construction industry has become a great demand for college education. Vigorously cultivating professional talents should be the focus of China's promotion of prefabricated buildings in the future.Colleges and universities should increase their efforts to cultivate talents and provide an endless stream of high-quality reserve forces for the development of prefabricated buildings.

VII. CONCLUSION

By establishing the construction quality evaluation index system of prefabricated buildings, it is beneficial to grasp the construction quality and strengthen the quality control of construction management. At the same time, it also provides some references for relevant departments to take corresponding measures. Based on the rough set theory, this paper reduces and selects the indicators and establishes the weights to deal with the problems of uncertain information and incomplete research data caused by the lack of relevant research on the construction quality evaluation of prefabricated buildings. A construction quality evaluation system for prefabricated buildings is established by combining quantitative and qualitative methods. It is proved that the evaluation system is scientific and reasonable

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by examples. This paper uses the literature research method combined with the prefabricated building construction technology to establish the universe of discourse, selects the simplified indicators for the quality evaluation system, and analyzes and studies the importance of the indicators to establish the weight, which mainly reduces the influence of human factors and ensures the credibility of the evaluation results. Since the relevant specifications for quality control of prefabricated buildings have yet to be improved, the scope of the evaluation system established in this article is relatively narrow; therefore, in future research, it is necessary to discuss further how to expand the scope of the universe.

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