

Research on Architectural Design Management Optimization Based on GA and DSM

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Abstract. In order to effectively solve the problems of high construction cost of prefabricated buildings, insufficient resources, and insufficient collaborative management and control capabilities. This paper conducts research on the factors affecting the construction cost of prefabricated buildings and the optimization of process management, analyzes the factors affecting the construction cost of prefabricated buildings, the hierarchical structure and the action path, constructs a lean construction process management framework system for prefabricated buildings, establishes an optimization model for the construction process management of prefabricated buildings, and proposes an integrated process management collaborative mechanism for prefabricated building projects. The research results are helpful to identify the factors affecting the construction cost of prefabricated buildings, clarify the ideas and methods for optimizing the construction process management, and maximize the benefits of the construction process. It provides a theoretical basis and important support for improving the optimization of the construction process management, collaborative management and lean construction of prefabricated buildings, and has important practical guiding significance for accelerating the industrialization of construction in my country.

Keywords: Optimization research; management system; genetic algorithm; prefabricated building; collaborative mechanism.

1. Introduction

With the continuous development of my country's economy, society and science and technology, the construction industry is also constantly innovating and changing. From the initial manual construction to the current industrial manufacturing, the professional technology of the construction industry is constantly innovating and improving, and prefabricated buildings have received widespread attention and recognition due to their many advantages such as lean design, factory production and assembly construction. Prefabricated components are the most important components and smallest units of prefabricated buildings. Their design and management work is crucial. The quality of the design results directly affects the subsequent production, transportation and on-site construction, and also determines the overall quality and benefits of prefabricated buildings [1].

2. Construction of Design Management Model Based on QFD-DSM

2.1 Quantitative Transformation Based on QFD-DSM

The organic combination of QFD and DSM methods can realize the early modeling and optimization of design management in the prefabricated building design stage, clarify the process goals of design management, and timely identify the information interaction relationship between various disciplines [2]. The combination of QFD and DSM methods, on the one hand, is an in-depth study of the QFD method, and on the other hand, it makes up for the fact that the existing DSM method does not consider the impact of changes in construction process requirements such as production, transportation, and construction on the design. It is also an important embodiment of the

lean design concept, thereby further ensuring the accuracy and rationality of the design results. Starting from QFD, after step-by-step derivation and quantitative conversion, the DSM process of function-product-process is gradually obtained, as shown in figure 1:

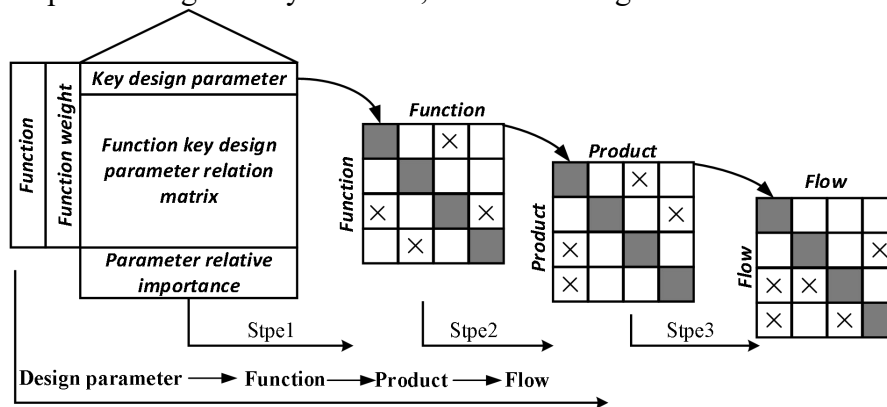


Fig.1 Quantitative conversion modeling based on QFD-DSM

2.2 Model Building

During the analysis process, it is necessary to pay attention to the direction of the impact of the change in design parameters on each function (positive correlation or negative correlation) [3]. For positive correlation, if the value of the design parameter is larger, the function value related to the parameter is higher, which is indicated by “+” after the grade value; for negative correlation, if the value of the design parameter is larger, the function value related to the parameter is lower, which is indicated by “-” after the grade value. Professional and technical personnel in the production, transportation, construction and other stages related to prefabricated buildings determine the weights of each functional element [3]. The formula for calculating the relative importance of the design parameters of prefabricated components of prefabricated buildings is as follows:

$$w_k = \sum_{i=1}^M F_i \cdot QFD(i, k) \tag{1}$$

$(i = 1, 2, 3, \dots, M), (k = 1, 2, 3, \dots, K)$

F_i : Indicates the weight coefficient of the functional element;

$QFD(i, k)$: represents the value of the row and column in the middle, indicating the dependency between the functional elements and the design parameters; respectively represent the number of design management functional elements and key design parameters in the design stage of prefabricated buildings [4].

The dependence strength between each functional element can be calculated from the weight coefficient of the functional element and the key design parameters, thereby constructing a functional matrix. The calculation formula is as follows:

$$F_{DSM(i,j)} = \sum_{k=1}^K w_k \cdot W_{j \rightarrow i} \cdot \frac{QFD(i, k)}{\sum_{k=1}^K w_k \cdot QFD(i, k)} \tag{2}$$

$W_{j \rightarrow i}$: If there is no constraint relationship, $W_{j \rightarrow i} = 0$; then, if there is a constraint relationship, $W_{j \rightarrow i} = 1$;

$F_{DSM(i, j)}$: The denominator of represents the sum of the dependencies between the function and all design parameters;

$F_{DSM(i, j)}$: The numerator of the function represents the sum of the dependencies between functions that only present a constraint relationship (i.e., the constraint dependency), which indicates the degree to which the function is affected by the change of function.

Based on the above analysis, on the basis of determining the weights of functional elements and the relationship between functional elements and key design parameters, a matrix of functions and key design parameters is constructed, as shown in figure 2.

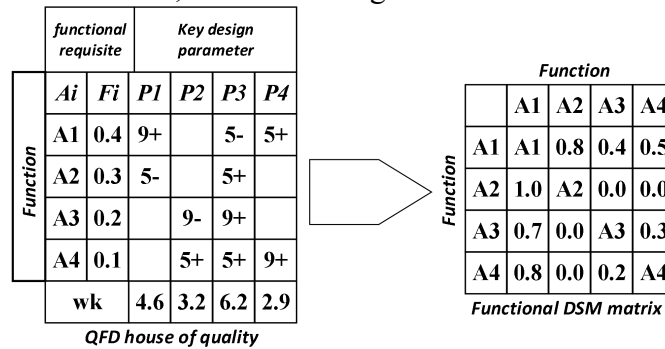


Fig.2 Schematic diagram of functional DSM derived from QFD

By using the dependency between functional elements, the domain mapping matrix between functional elements and product elements, and the transposed matrix of the product element matrix is derived, and the calculation formula is as follows:

$$C_{DSM(I,J)} = \sum_{k=1}^m DMM(I, i) \times \sum_{j=1}^m (F_{DSM(i,j)} \times DMM^T(j, J)) \quad (3)$$

DMM^T: Represents the transposed matrix of DMM;
m: Indicates the number of functional elements.

3. Research on Design Management Optimization Based on GA and DSM

3.1 Design of Optimization Method Based on GA

The new optimization method mainly solves the sorting problem of prefabricated building design management activities. Any work order design task can be considered as a solution. The total number of design tasks is, which can be encoded in binary format. The value of each coding bit is used only once for each letter, and the length of the gene code chain is. According to the fitness function value TCC of each gene individual, the larger the fitness value, the better the gene individual is, and the greater the probability of being selected. The fitness value is selected by roulette, and the generated offspring genes must meet the requirements of gene sorting and uniqueness. Therefore, when designing the sorting optimization crossover algorithm, it is necessary to randomly select a truncation point first, as shown in figure 3 [5].

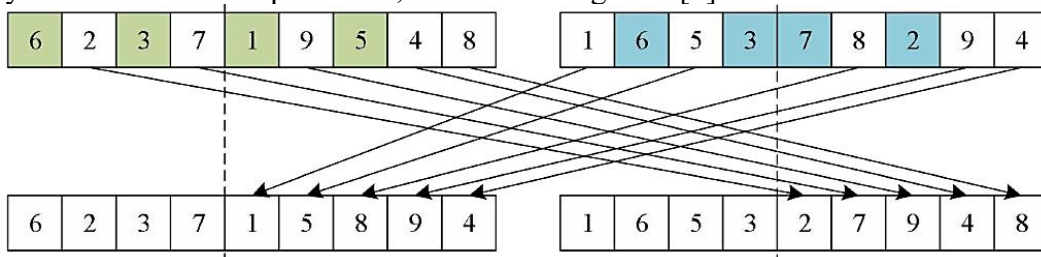


Fig 3. Example of cross operation

Based on relevant research and consideration of actual engineering conditions, single-point mutation operator, Shift mutation operator and multi-point mutation operator are used to randomly exchange the positions of 2 or 4 genes at different positions in the chromosome under certain probability requirements to obtain mutation operators, and new individuals are generated through mutation. The algorithm is improved to improve its global convergence.

3.2 DSM Process Optimization Based on GA

At present, the optimization of prefabricated component design management tasks in the prefabricated building design stage mainly depends on the experience of designers [6]. Due to the many uncertainties in the dependencies between design tasks, such as frequent design rework and secondary rework in the design management process, this paper introduces the rework probability matrix RP (Rework Probability) and the rework impact matrix RI (Rework Impact) to further describe the coupling dependency between complex activities, as shown in figure 4.

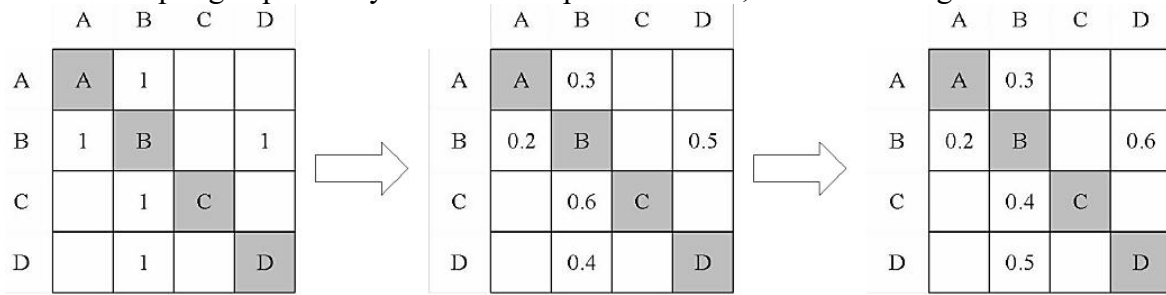


Fig.4 Schematic diagram of different DSM matrices

4. Model Validation and Case Analysis

4.1 Project Overview

Taking a prefabricated residential project in the Innovation Port area as the engineering background [7]. The prefabricated components mainly include prefabricated shear walls, composite slabs, prefabricated stairs, prefabricated balconies and other components, as shown in figure 5.

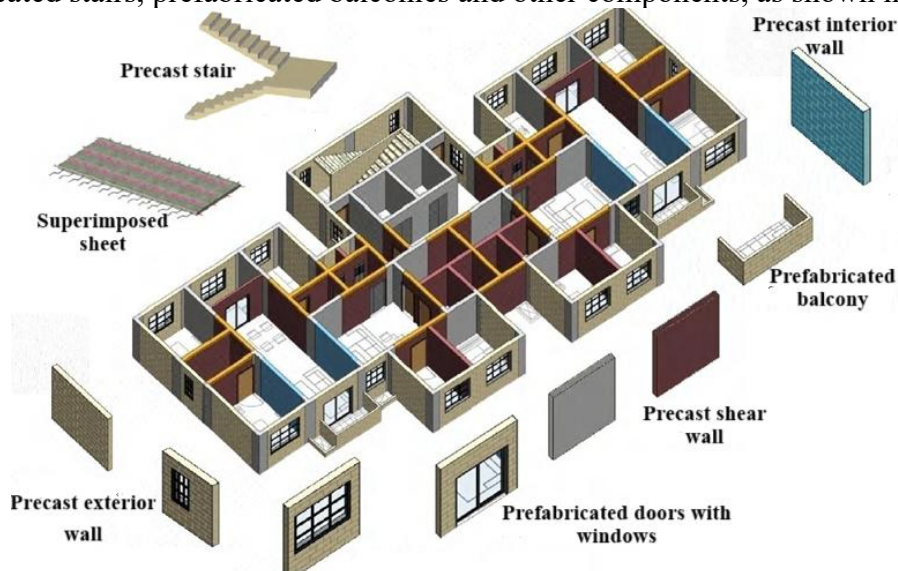


Fig.5 Schematic diagram of prefabricated components in prefabricated buildings

4.2 Build a Process DSM Matrix

In order to achieve the step-by-step analysis of the function-product-process of prefabricated building design management activities to obtain the functional element DSM matrix, expert judgment is used [8]. There is a floating-point value, which represents the possibility of rework between design management activities in the prefabricated building design stage. The corresponding rework probability $RP(i, j)$ matrix and rework impact intensity $RI(i, j)$ matrix describing the rework between design management activities are obtained, as shown in figure 6.

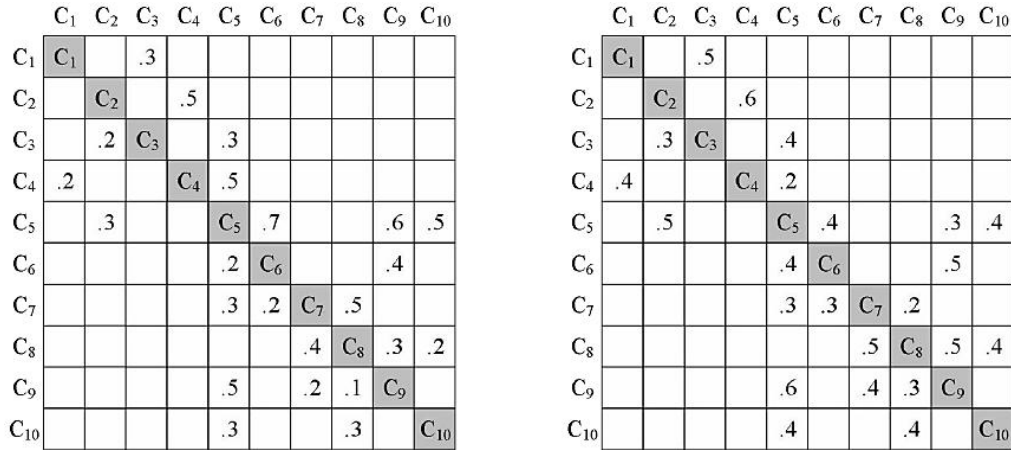


Fig.6 DSM rework risk matrix

4.3 GA-DSM model optimization solution

According to the research and project consultation on the design management process of prefabricated buildings, the design management process mainly consists of 10 task processes from C1 to C10, and the cost and time required for each task process are shown in Table 1.

Table 1. Data related to prefabricated building design management tasks

Serial Number	Design task	Duration (days)	Cost (ten thousand yuan)
C1	Conceptual design	10	2.4
C2	Scheme design	30	7.2
C3	Preliminary design	20	4.8
C4	Construction drawing design	70	25.2
C5	Component deepening design	40	14.4
C6	Production mold design	10	2.4
C7	Construction transportation design	4	1.2
C8	Component stacking design	3	7.2
C9	Component lifting design	4	1.2
C10	Component support design	3	9.6

According to the inherent characteristics of design management tasks in the design stage of prefabricated buildings, the knowledge and experience of design managers, and the information interaction between upstream and downstream activities, the initial process of design management activities was constructed based on lean design theory, combined with quality function deployment and design structure matrix method [9]. The probability density of cost and duration before and after optimization and the cumulative probability density curve are shown in figure 7.

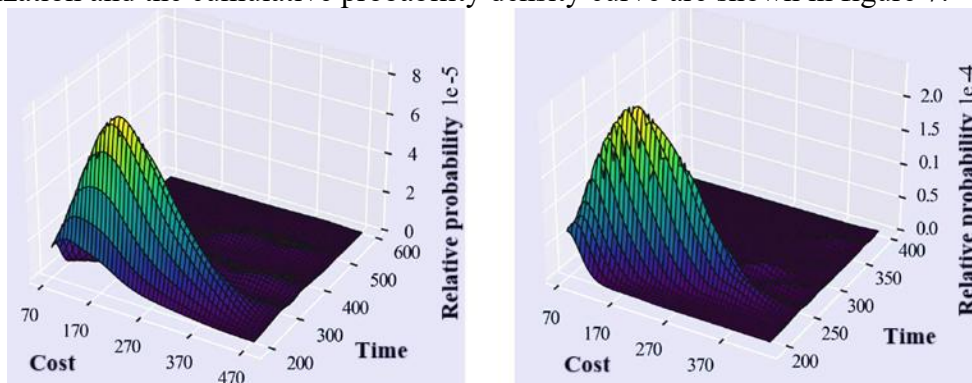


Fig.7 Optimizing the joint probability distribution of time cost before and after optimization

In the early design stage, prefabricated component factories and engineering construction units need to intervene and cooperate in advance, taking design as the lead to maximize the advantages of the engineering general contracting model, which not only helps to improve the efficiency of information interaction and collaborative management between design management and upstream and downstream activities, but also plays an important role in cost reduction, efficiency improvement and lean management of the prefabricated building construction process [10].

5. Conclusion

According to the complexity and uncertainty of the design management tasks in the prefabricated building design stage, as well as the dependency between information in different links, this paper uses the quality function deployment method (QFD) to reflect the dependency between elements in different dimensions, and uses the design structure matrix (DSM) to describe the feedback and rework iteration characteristics between different design tasks, so as to clarify the objectives of each task. By coordinating the upstream and downstream tasks of the prefabricated building design management industry chain, avoiding design rework, reducing resource consumption, and reducing construction costs, the design management task process of the prefabricated building design stage is made more orderly and reasonable. In the process of prefabricated building design management, in order to ensure the smooth implementation of various design management tasks, design management personnel should deeply consider and coordinate the downstream links such as the production, transportation and on-site assembly of prefabricated components. At the same time, the prefabricated component factory and engineering construction unit need to intervene and cooperate in advance to enhance the information interaction and feedback between various links. The integration and leanness of design management in the design stage can improve construction efficiency, reduce resource waste, and reduce construction costs.

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