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Construction of Lean Control System of Prefabricated Mechanical Building Cost Based on Hall Multi-dimensional Structure Model

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Based on the systematic idea of Hall's multidimensional structure and the theory and practice of prefabricated building cost lean management, the prefabricated mechanical building cost lean control system based on Hall's multidimensional structure model is proposed and constructed. The application of the lean management of the hall multidimensional structure model from the perspective of the time dimension, logic, and knowledge dimension. The example analysis results show that the original design components and the number of open modes is 72, the optimized types of components and the number of open modes is 51, reduce 21 mold machining, mold costs were reduced by about 25%. The number of original design components and the lifting times of components is 129 kinds, the number of components and lifting of components is 103, the number of components per layer was decreased by 26, lifting time is shortened by about 20%, the comprehensive construction period is shortened by more than 40 days, improve the management efficiency, lean cost control of the project plays a positive role. It provides a reference for the lean control system management of the hall multidimensional structural model

Povzetek: Razvit je vitki nadzorni sistem za gradnje na osnovi Hallovega multi-dimenzionalnega modela.

1 Introduction

In recent years, with the orderly progress of the transformation and upgrading of the construction industry, prefabricated buildings have become the direction of sustainable development of the construction industry due to the advantages of energy conservation, environmental protection, green, and efficiency [1]. However, the development of prefabricated buildings has also brought a series of quality management problems, such as the transformation of the extended construction mode of the construction industry chain [2]. BIM technology as the information development of construction industry technology, applied to the project construction design, construction, management, can be integrated into the construction process of prefabricated building, realize the different links of construction industry chain information exchange, coordination, and simulated in the virtual environment, control the real project construction. With the maturity of the development system of prefabricated buildings and the improvement of the development scale, the cost is lower than that of traditional cast-in-place buildings, among which the cost of prefabricated buildings in the United States is only half the cost of traditional cast-in-place buildings [3]. In economic economics of prefabricated buildings Tezel, A. through the mail to 100 construction units, design company, prefabricated component manufacturers and workers questionnaire, detailed analysis of the use of prefabricated building system, most of the contractors think in the use of prefabricated building system, if the staff has a high degree of specialization and information communication between the participating units smooth, prefabricated building system will reflect more economical [4]. Xing *et al.* outlined the development situation of prefabricated housing and prefabricated and traditional cast-in-place building in cost and construction process difference, with the help of cost software and fixed cost difference of cost analysis, and the key factors related to cost sensitivity analysis, and then affect the key factors of cost put forward suggestions on the control [5]. In the prefabricated building design phase. Goger and Bisenberger on the basis of fully considering the prefabricated building cost control, the design method is optimized. In the production stage of prefabricated components, the economic advantages of prefabricated buildings are analyzed from the production stage of prefabricated components, which shows the broad development prospects of prefabricated buildings and the huge economic benefits brought by [6]. The main reason for the high cost of prefabricated buildings than the traditional cast-in-place buildings is the high fixed asset investment and industrial worker training cost of prefabricated component factories. In the logistics stage of prefabricated components, for prefabricated building prefabricated components in the process of logistics due to not smooth information transmission caused by distribution delay, repeated detection, stacking error phenomenon to increase labor cost and mechanical costs, RFID technology combined with GPS technology to the logistics transportation of prefabricated components, can quickly and simple positioning of prefabricated building prefabricated components, the site management of prefabricated components. Based on the basis of the present research, this paper to construct a lean control system based on the Hall multidimensional structure model, from the perspective of a time dimension, logic, and knowledge dimension application, through example analysis results show that combining the participants of various stages, recycling seven logical steps, and constantly refine cost management objectives and operation to achieve the goal of overall cost control.

The rest of this article is organized as: Section 2 presents the related works in various domains. Section 3 consists of methods comprising the concept and flowcharts of the proposed 3D structural model. Results and analysis are discussed in section 4 followed by concluding remarks in section 5.

2 Related work

The construction manufacturing business is considered the major reason for the degradation of the environment [7]. The construction businesses consume an excessive number of natural resources and are responsible for the wastage of C&D (construction and demolition) [8]. In the year 2018, approximately 600 million tons of waste is reported in the United States, even though this waste can be recycled and reused. In one study it is discussed that approximately 50% of C&D waste is recycled and reused and transferred to energy facilities [9]. It is estimated that approximately 40% of C&D waste after the recycled and reused treatment is transferred to the landfills without any further direction and use [10]. It is noticed from the observation that the adverse environmental impacts of C&D can be reduced by maximizing the recycling and reuse process [11]. Economic waste management activities can also help in reducing C&D waste [12]. Instead of giving attention to the issues of C&D waste, the low recycled and reused measures of C&D are considered to be major limitations. In the United States, the recycling of concrete material is estimated at approximately 55% [13]. The design of the construction waste management system is very essential for the recycling and reusing of industrial waste and to divert the industrial waste from landfills to reusability [14]. An efficient system for industrial and construction waste management systems incorporates the estimation of recycling and reusing quantities and the methods for storing and reducing construction waste [15]. This project is not limited to industrial applications but the overall growth of social life with the integration of the Internet of Things, AI, and robotics [16-19].

Moreover, such a system can also provide information about the stakeholders who are responsible for waste disposal. The benefits of recognition of such a system also present their implementation challenges in terms of delay and productivity [20]. In order to meet all such requirements, efficient planning is the foremost requirement to address issues such as budget, safety, and schedule [21]. BIM (building information modeling) is recognized as the main expansion for Construction, architectural, and engineering industries [22]. Over the last 10 years, BIM technology has gained attention and the majority of BIM applications are considered for construction waste management systems [23]. The planning of construction waste management can be improved by several capabilities of BIM such as simulation, visualization, and parametric modeling. However, one study on the requirement of BIM for construction waste management presents that the advanced computer-aided tools have the capability for enhancing the performance of construction waste management throughout the several phases of development [24]. An exhaustive review presents the application of BIM toward construction waste management, highlights that there is less evidence of such systems that can discretize the generation of construction waste for recycling and reusing without depending on some external issues, and addressing precise actions in the schedule of construction and hence admitting reuse of construction waste [25]. The authors have presented a four-dimensional BIM model for enhancing the recycling and reusing of construction waste and addressing the previous limitations. Their work considers on-site reusing and off-site recycling of construction waste and specific actions are indicated for admitting the reuse of construction waste [26]. With the integration of the temporal dimension to BIM, the generation of construction waste can be imagined as the activities of construction, therefore enabling the construction waste planning for on-site reusing and off-site recycling [27].

The four-dimensional BIM application in the planning of recycling and reusing is demonstrated for non-residential case studies in the streams of drywall and concrete [28]. These waste streams are nominated as they are the largest construction waste streams that are produced in the US. Concrete possesses a high potential for both recycling and reusing, whereas drywall possesses a good potential for recycling only. The maximum resource recovery can be achieved by the efficient planning of the construction waste recycling and reusing process, and thereby reduction can be observed in landfills of construction waste [29]. The prime objective of this study is to highlight the planning of construction waste for recycling and reusing for projects by designing a model based on a temporal and visual approach by using the available data of construction projects. The proposed model is also considered to be applicable for several projects that are independent of their locations. The major contribution of this study is to provide an approach for the identification of on-site reusing activities of construction waste.

3 Method

In this section, the concept of the multidimensional model and the flowchart of the proposed 3D structural model is described.

3.1 Cost structure of the prefabricated building, Hall 3D structure theory, and lean cost management thought

C. Cost composition of the prefabricated building

Prefabricated building cost refers to all the costs involved in the life cycle of the prefabricated building project. It can be divided into the following four categories: planning and design cost, construction and production cost, warehousing and logistics cost, and construction and installation cost. Therefore, lean management of these processes is a key to reducing the cost of prefabricated buildings [30].

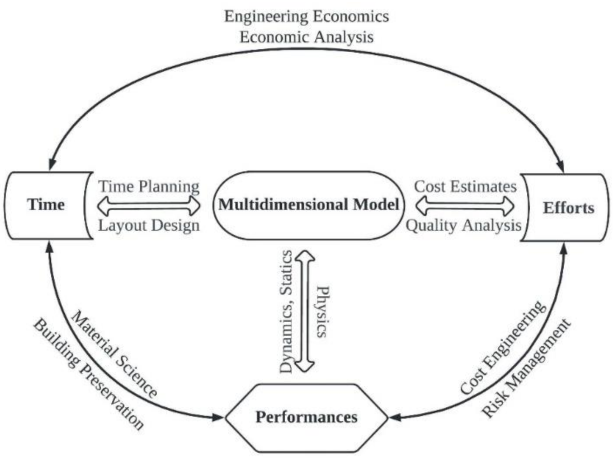

Figure 1: Concept of a multidimensional model

The concept of the multidimensional model is depicted in figure 1. It consists of a cycle of time, effort, and performance. In the proposed model, the time and effort cycles combine the process of planning, layout design for the estimation of cost parameters, and quality analysis considering economics. Effective planning and constant efforts lead to quality products and improved performance is achieved through dynamics, physics, and statics.

D. Hall 3-dimensional structure theory

The theoretical method of 3-dimensional spatial structure solves the management problems of planning, organization, and coordination of some large and complex projects. Hall's three-dimensional structure theory divides the objects of system engineering research into knowledge dimension, time dimension, and logic dimension according to different stages, knowledge, and logic methods used. Using relevant expertise provides effective analysis tools for solving large and complex projects.

E. Lean cost management thought

Compared with the traditional cost management method of construction projects, lean management pays more attention to the cost management of the whole process of the project, so using the idea of lean management for cost management is more comprehensive. Lean cost management is studied in the bidding, design, construction, logistics and other aspects of construction projects analyze the factors affecting cost at each stage, and then puts forward targeted cost management methods, so as to achieve the purpose of improving efficiency and reducing cost [31].

3.2 Construction and analysis of the Hall 3 D structural model

3.2.1 Time dimension

In this section, the working of the proposed design is discussed. The proposed design is divided into four categories as depicted in figure 2.

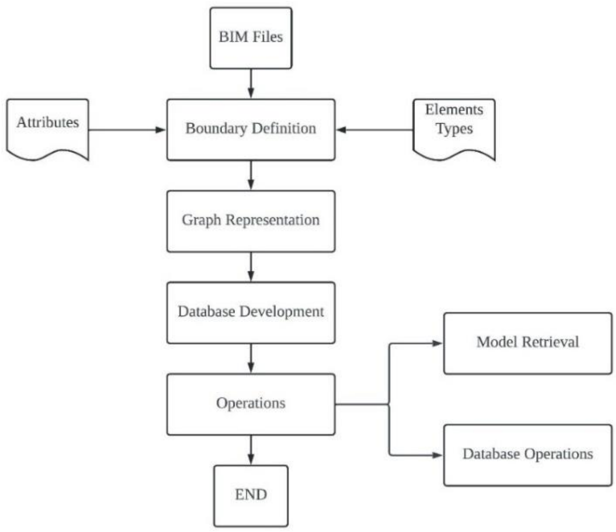

Figure 2: Proposed design of Hall 3D structural model

In the first step, system boundaries are determined through the inputs of selection attributes and building elements. In the next step, the information from the selected attribute or element is represented graphically and the same process is repeated for each module. In the third step, the graphical information is imported to a graph database. In the next step, graph-based operations are performed for module retrieval and performing other graphical applications.

A. Cost management in the planning and design stage

The beginning stage of the cost composition of prefabricated construction projects is the planning and design stage. Usually, at this stage, the preliminary work should be strengthened, and the planning and design should be made according to relevant knowledge and regulations, so as to obtain the minimum investment and obtain the maximum income. According to the lean cost management idea, the following two methods are put forward in deepening the design: method-is to implement the parallel design. In the prefabricated building planning and design stage, the relevant subjects of each stage can send technicians to participate. Methods Second, fine management based on BIM, collaborative operation of each major; using BIM technology to find omissions and collision inspection is conducive to reducing the cost generated by design change; the information platform built by BIM technology, establish a standard component library, realize the standardized design and reduce between later design cost [32].

B. Cost management in the construction and production stage

The cost of the production stage is the largest part of the life cycle cost of prefabricated buildings. Prefabricated components use the following lean cost management methods in the production stage: Method first, is to implement standardized production, which refers to collecting product information, ensuring the supply of raw materials, and conducting standardized mass production according to the information in the component information database. Methods second, to conduct lean supply chain management and establish BIM raw material supply information sharing platform.

C. Cost management in the warehousing and transportation stage

The cost management in the warehousing and transportation stage is mainly realized through the implementation of nine on-time productions and strengthening the protection of component transportation. The implementation of on-time production mainly refers to the reasonable planning of the production and completion time of prefabricated components and controlling the one-time production, so as to effectively use the storage space and reduce the inventory cost. Strengthening the transportation protection of components refers to the prefabricated components that are transported to the construction site after the production of the factory, and conduct strict quality checks on the loading stage and transportation stage to reduce the cost of secondary repair.

D. Cost management in the construction and assembly stage

The prefabricated components should be assembled after being transported to the construction site. At this stage, the I site should be managed in an orderly manner, and various construction information should be organized and coordinated to ensure normal operation. The following methods are proposed for the cost management of the construction and assembly stage based on the lean management method: 5s site construction management, which is very efficient for the site management of prefabricated construction projects and is synchronously controlled through the integration of various aspects of information. Formulate a reasonable prefabricated hoisting plan, and the prefabricated components to be transported to the construction site shall be assembled in time, otherwise, the site will be occupied, and the storage cost on the site will be increased. The application of s site management method in the construction and assembly stage of prefabricated construction projects is shown in Table 1.

Designation	Concrete operations
Arrange	Organize and distinguish the relevant items on the site, and remove the irrelevant items on the site
Rectify	Place items in a reasonable location for easy search
Clear	Clean up the dust and garbage on the site to ensure that the site is clean and tidy
Cleaning	Continue to thoroughly implement the three links of sorting out, rectification, and cleaning
Accomplishment	Cultivate the comprehensive quality of relevant personnel on-site and improve the mental outlook of employees

Table 1: 5S practices for managing prefabricated building sites

3.2.2 Logical dimension

The logical dimension refers to the thinking procedure that the work content should be followed in each stage of the time dimension, that is, refers to the thinking process of each stage of cost management of lean management thought. When using system engineering ideas to solve engineering problems, logic dimensions can be divided into the following steps, as shown in Table 2.

Step	Concrete operations
Make clear the problem	The main purpose is to set the completion goals of various stages, schedule, consider possible problems, and prepare measures to respond
Set goals	After determining the overall goal, the objectives need to refine the goal and develop phased goals at each stage
Comprehensive plan	According to the characteristics of the target, the scientific scheme comparison method is used to finally determine the optimal scheme
Systems analysis	Considering the advantages and disadvantages of different schemes, then deeply analyze the unique advantages of each scheme, and comprehensively judge the efficiency and ease of completion of each scheme according to the corresponding indicators and rank

Scheme comparison	The optimal scheme is chosen according to the different objectives and the constraints existing in the actual process
Make policy	After systematic analysis and comparison of numerous schemes, the optimal implementation of the research problem is determined
Put into effect	Use the final scheme as the implementation scheme of the cost management site of the prefabricated construction project

Table 2: Steps for logical dimension

3.2.3 Knowledge dimension

The knowledge dimension of lean management of prefabricated buildings mainly includes project knowledge, financial knowledge legal knowledge, and management knowledge. Project knowledge refers to the process to be familiar with the design, production, transportation, and assembly stages of matching construction projects. Financial knowledge refers to discussing the cost composition of all stages of the prefabricated building project, analyzing the main factors affecting the cost, analyzing the content of cost management from the micro and macro perspective, and coordinating the interests of the participating subjects. Legal knowledge refers to the life cycle of prefabricated construction projects, from the bidding stage to the project completion stage, various legal risks should be avoided. Management knowledge refers to the flexible use of lean management theory, including lean value management theory and lean management characteristics [33].

4 Results and analysis

This section includes the result and analysis of the proposed model consisting of example analysis and risk assessment.

4.1 Lean cost management model of the prefabricated building based on Hall 3D structure

A. Prefabricated construction

Treated project cost management hall 3D structure model activity matrix hall 3D structure model by combining time-dimensionality, logical dimensionality, the effective combination of intellectual dimension, it may clearly understand a certain state in space and have targeted research cost management mode and method. The three-dimensional structural model can also choose two dimensions to simplify the two-dimensional planar structure, which can more intuitively understand the connection between two dimensions. According to the matrix theory, select the two dimensions of time and logic dimensions, cross the two dimensions across the plane $m * n$ matrix of each element [34].

Using system engineering theory knowledge, the four phases of the time-dimensional time dimension in assembly buildings and seven steps of logical dimensions constitute 28 elements of the two-stage building profit cost management activity matrix, such as Table 3 Show, a_{ij} indicates the specific activity of lean cost management at all stages.

Time dimension	Logical dimension						
	Make clear the problem	Set goals	Comprehens-ive plan	Systems analysis	Scheme comparison	Make policy	Put into effect
Planning programming	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	a_{16}	a_{17}
Construction and production	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}	a_{26}	a_{27}
Storage and transportation	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}	a_{36}	a_{37}
Construction assembly	a_{41}	a_{42}	a_{43}	a_{44}	a_{45}	a_{46}	a_{47}

Table 3: Lean cost management activity matrix for prefabricated buildings

B. Assembly building cost management model based on Hall 3 D structure

Based on the above cost management ideas of prefabricated building projects of Hall's three-dimensional structure from three dimensions of the time dimension, logic dimension, and knowledge dimension, all elements are organically combined to build the lean cost management model of corresponding prefabricated building projects. Prefabricated building projects involve a large number of participants and complex uncertainties. With the advancement of all stages in the assembly time life cycle, the subject and object of cost management work have changed accordingly, so richer and extensive knowledge support is needed. Lean cost management thought closely connects the scattered stages through the knowledge dimension and time dimension. The logical dimension runs through all stages of prefabricated construction projects. For the cost management objects of different time dimensions, combined with the participants in each stage, seven logical steps are recycled, continuously decompose, and refine the cost management objectives and operations, in order to achieve the target of the overall cost control [35].

C. Example analysis

Take a single building as an example to analyze the benefits obtained in cost control. As shown in figure 3, the original design components and opening types are 72,51,51,21 molds, 125%, 129 components, 103 components, 26 components, lifting time by about 20%, and 40 days, improving management efficiency and promoting lean control of the project cost.

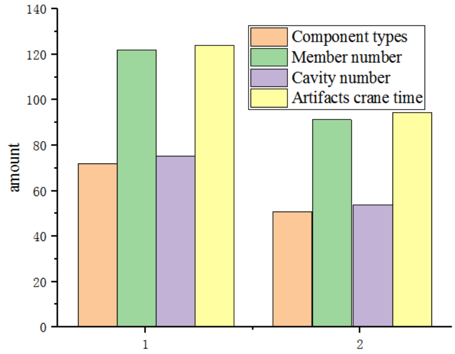

Figure 3: Comparison between original design and optimization

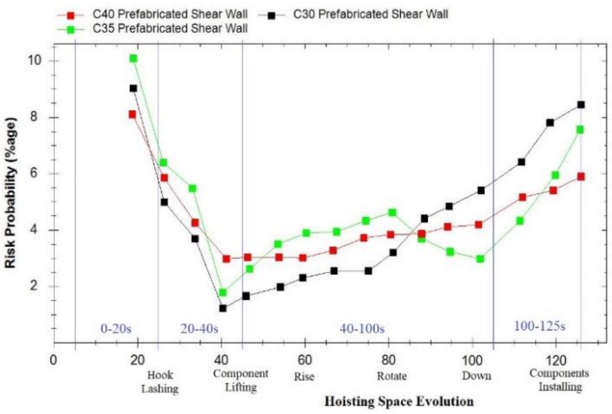

Figure 4: Safety risk assessment

In the very first step, the BIM model is handled. This study changes over the BIM model into IFC design records, then the arrangement documents are parsed and handled in JavaScript. The BIM model was carried on the website page involving WebGL as depicted in figure 4 after the lightweight of the BIM model. This structure gives an effective information connection strategy to plan multidimensional data on location to virtual model in time. Moreover, the system can rapidly send feedback and estimation results of virtual space to directors and administrators, and work fair and square of well-being the executives.

5 Conclusions

This paper is based on systematic ideas of hall 3-dimensional structure, a Study on the construction of a lean control system of prefabricated machinery construction cost, through an analysis of the hall 3-D structure model, and the construction of a prefabricated building cost management model based on the hall 3D structure, benefit analysis of one building. The results show that the original design components and the number of open modes is 72, the optimized types of components and the number of open modes is 51, reduce 21 mold machining, mold costs were reduced by about 25%. The number of original design components and the lifting times of components is 129 kinds, the number of components and lifting of components is 103, the number of components per layer was decreased by 26, lifting time is shortened by about 20%, the comprehensive construction period is shortened by more than 40 days, improve the management efficiency, lean control of the cost of the project plays a positive role. Combined with the participants in each stage, seven logical steps are recycled to continuously decompose and refine the cost management objectives and operations, so as to achieve the goal of the overall cost control. Due to the limited time and level, the research in this paper still has some shortcomings. In the future, BIM technology can be combined with wireless RF identification (REID) technology, the internet of things, a global positioning system (GPS), and other information technologies, to form the whole construction process of a prefabricated buildings-a system that can identify, locate and monitor prefabricated components automatically and in real-time, and more effectively control the cost of prefabricated buildings.

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