

Control Management of Construction Cost of Prefabricated Residential Buildings

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ABSTRACT: The acceleration of construction of cities and towns motivates the development of the construction industry. Prefabricated residential building is extensively concerned by the public for its small damages to the surrounding environment and high quality. In this study, different construction stages of the prefabricated residential building were analyzed, and factors influencing the construction cost in different stages were discussed. The construction technique, speed, civil work cost and environmental benefits were compared between the traditional concrete building and the prefabricated residential building. Moreover the differences of costs in different stages were compared in a real case. Several effective measures for controlling construction cost were put forward. The results demonstrated that the cost of the prefabricated residential building was much lower than that of the traditional concrete building. The suggestions for reducing construction cost can provide a reference for similar projects.

KEYWORD: Prefabricated, Residential buildings, Project cost, Difference analysis

1 INTRODUCTION

The rapid development of our economy has accelerated the construction of cities and towns in recent years, thus enabling the development of the construction industry. The traditional construction means has relieved the pressure of urbanization because of utilization of local materials and convenient processing and manufacturing. However, environmental protection is the mainstream of the current development. The traditional cast-in-place architecture has gradually replaced by prefabricated buildings because of its large construction difficulty, large demands of workers, high cost and large construction waste. But currently the mixture of the traditional and prefabricated building technologies is more frequently used. Prefabricated building technology is an automatic planning model of the assembly construction process based on geometric reasoning put forward by Hu [1]. The whole building is firstly disassembled into different components. The components of the building are produced and processed in factories in advance. Then they are transported to the construction site after maintenance and assembled using mechanical equipment using pre-determined construction scheme.

In the study of Yuan [3], the concept and process of the design of prefabricated buildings which were based on the parameters provided by building information model (BIM) were introduced. Kim [4] put forward the corresponding assembly tools for prefabricated buildings to improve safety. Samani et al. [13] assessed the related costs of buildings with life cycle cost analysis (LCCA) and found that prefabricated buildings had lower operating costs. There are many factors affecting the efficiency of prefabricated building. To ensure the completion of the prefabricated building on time, Wang et al. [2] have studied factors affecting the construction progress from the aspects of construction, design and construction management. They found that the insufficient coordination between the contractors, improper handling process, unclear division of labor and insufficient experience of builders had large impacts on the construction progress.

In prefabricated architecture, early design is very important for cost saving. Wang [7] proposed a method of assembly sequence planning based on BIM by combining BIM with process engineer experience. This method could help process engineers to make reasonable prefabricated assembly from the perspective of visualization. Moreover the operation process of the method was illustrated using the prefabricated concrete building model. The purpose of

BIM is to form a coherent construction information platform through rationalizing the construction projects and to making the production and project life cycle management scientific [8]. Through the analysis of the actual cases, this paper compared the cost difference between the assembly and the traditional cast-in-place buildings and analyzed the reasons. Finally, the effective measures were put forward to reduce the cost.

2 ANALYSIS ON DIFFERENT STAGES OF PREFABRICATED CONCRETE RESIDENTIAL BUILDING

The flow of prefabricated concrete building includes design stage, production stage, transportation stage and construction and installation stage.

2.1 Design stage

In the design stage, the components of the building should be disassembled and deeply designed based on construction drawings. The design should satisfy drawings of engineering design standard and component processing of factory production. The possibility and convenience of transportation increases the workload and difficulty of design. The design can directly affect the cost of a project.

Design of prefabricated buildings should consider the configuration and deep design of all components and select out the optimal component disassembly scheme after considering factors such as categories of components, manufacturing technique, equipment state and manufacturing cost. The disassembly reasonability will directly affect the cost of prefabricated buildings. Generally, the overall structure of prefabricated buildings was designed firstly, and then component disassembly and integration drawings were designed.

2.2 Production stage

In the construction of prefabricated buildings, components are produced firstly and then transported to construction sites for assembly, which seems like an assembly line. In this way, multiple professional processes can be carried out at the same time.

Different prefabricated buildings are produced in different methods. Production method related factors such as material consumption, operation difficulty and skills and salary of workers have large influence on production cost. Therefore proper production means should be selected for different components. It is concluded after field research on multiple prefabricated component production factors that production technique form and technological process have great influence on the cost of prefabricated components.

Compared to cast-in-place technology, prefabricated components can more effectively solve the possible quality problems in the process of production. Different manufacturing technologies and methods can affect cost.

2.3 Transportation stage

Transportation is inevitable because the components manufactured in factories need to be assembled in construction sites. The components will suffer four stages, i.e. storage in factories, road transport, temporary storage in construction sites and hoist in position, from finished to installation. Reasonable planning of the four stages can reduce the occupation area of the components and achieve smooth workflow, leading to reduced cost. Transportation distance and condition and placement quality will affect transportation cost. Therefore handling transportation well is necessary for reducing cost.

2.4 Construction and installation stage

The construction method and technology in the construction stage will directly affect the construction organization design and installation cost.

The complicated installation technology, installation procedure and connection of prefabricated components can be simplified on the premise of satisfying design standardization to reduce construction material consumption and cost of labor and improve working efficiency.

3 ANALYSIS OF PROJECT CASE

3.1 Project profile

3.1.1 Project introduction

A project in Liaocheng, Shandong, China, which had 13 overground layers and 1 underground layer, was taken as an example. Floor 1 adopted cast-in-place shear wall, and floor 2 to 13 (standard floors) adopted prefabricated shear wall; the building area was 950 m². The components were connected using double casing. The floor was constructed using PK prestressed concrete composite boards, the external walls were constructed using prefabricated sandwich thermal insulation wallboards, and the load bearing walls inside the building were constructed using prefabricated shear plates. The division walls were constructed using lightweight wall plates, and the stairs were prefabricated. An industrialization base was entrusted to manufacture all the prefabricated components which were needed in the construction process in advance. Then the components were transported according to the schedule and assembled in the construction site.

3.1.2 Calculation of cost of single layer

The construction parameters except construction area, unit price, building height and number of floors

shown in Table 1 were the common construction parameters of general buildings.

Table 1 – The technical parameters of the project case

Category of structure	Prefabricated shear wall structure
Floor height	Floor 1: 3.5 m; floor 2-13: 3 m
Number of floors	13 overground floors, 1 underground floor
Building height	39.5 m
Classes of seismic measure	Class 5
Fireproofing grade	Grade 3
Earthquake fortification intensity	Grade 7
Basement waterproof grade	Grade 3
Main prefabricated components	Prefabricated partition wall
	Prefabricated superimposed sheet
	Prefabricated stairs, ladder beam and landing
	Prefabricated shear wall
Construction area	950 m ²
Unit price	258 yuan/m ²
Remark	See table 2 for details of unit price

The installation costs of the prefabricated part and cast-in-place part per standard floor were calculated,

and the calculation results are shown in Table 2 and 3.

Table 2 – The cost of the prefabricated part

Name	Items	Unit price (yuan/m ²)	Total price (yuan)	Remark
Hoisting	Labour charges, installation equipment, electricity box, wires	41	38950	Not include the cost of tower crane and hoist
Revolving material		26	24700	Include batten, template and support bracket
Rebars	Manufacturing, installation, auxiliary materials, electrical arc welding and waste treatment	18	17100	Not include cost of rebar materials
Concrete	Vibration, mash, maintenance, cleaning construction site	11	10450	Not include the cost of concrete material
Auxiliary material	Devices stipulated by the construction standards such as safety belt, safety helmet and foaming agent	9	8550	Include mounting pad
Woodworking	Manufacturing, installation, abrasive, disassembly, auxiliary materials, devices, etc.	50	47500	
External frame	Manufacturing, installation, disassembly, auxiliary machines, temporary edge protection	9	8550	
Support bars		10	9500	
Safe and civilized construction	Protect finished products, put materials in order, pay attentions to hygiene condition of construction site, strengthen patrol	8	7600	
Management cost	Field management, coordination	9	8550	
Profit		13	12350	
Grouting	Related grouting machines	6	5700	
Small machines		10	9500	

Paying off		4	3800	
Tax point		15	14250	According to national standards
Total		258	245100	

Table 3 The cost of the cast-in-place part

Name	Cast-in-place concrete	Impermeable concrete in kitchen, balcony and bathroom	Cement	Pedestaling slurry	Sand	Cost of labor	Cost of tower crane
Work amount	130	13	0.9	0.9	2.3	820	10
Unit	m ³	m ³	t	t	m ³	m ²	day
Unit price (yuan)	330	345	390	1810	135	250	1700
Total price (yuan)	42900	4485	351	1629	310.5	205000	17000
Name	Rebar (level 3 steel, diameter 6 mm)	Rebar (level 3 steel, diameter 8 mm)	Rebar (level 3 steel, diameter 10 mm)	Rebar (level 3 steel, diameter 14 mm)	Rebar (level 3 steel, diameter 16 mm)	Cost of labor of tower crane driver	Total price
Work amount	0.25	8.666	1	6	0.8	10	
Unit	t	t	t	t	t	day	
Unit price (yuan)	3535	3457	3455	3129	3075	450	
Total price (yuan)	883.75	29958.362	3455	18774	2460	4500	340597.612

The total cost of single prefabricated layer was 245,100 yuan, while the total cost of single cast-in-place layer was 340, 597.612 yuan. Obviously, the prefabricated layer was cheaper. Though the cost might fluctuate because of some factors, the influence was little; it was because that the costs of all the items of the prefabricated layer were cheaper.

3.1.3 Calculation of construction period

The first floor in the case was estimated to be finished in 10 days. Floors 2 to 13 were prefabricated; every floor was estimated to be finished in 5 days. The estimated construction period was 70 days. The construction order was designed according to the size of construction work and structure. The progress schedule was as follows.

The construction period of single layer was divided into three stages.

In the first day, 50 wallboards of the first-stage construction section were installed.

In the second day, sleeve grouting, setting of support frame and colligation of post-cast strip rebars of the first-stage construction section started. 50 walls of the second-stage construction section were hoisted in the morning, and the post-cast strip formwork reinforcement was performed in the afternoon.

In the third day, sleeve grouting, setting of support frame, colligation of post-cast strip rebars and formwork reinforcement of the second-stage construction section started. 30 walls and superposed beams of

the third-stage construction section were hoisted in the morning, and sleeve grouting and stairs hoisting of the third-stage construction section were performed in the afternoon.

In the fourth day, 55 superimposed sheets were hoisted, and water and electricity pipelines were pre-embedded. Slab joint formwork was constructed in the morning, and the upper rebars of the floorslab were bound in the afternoon.

In the fifth day, 47 superimposed sheets were hoisted, water and electricity pipelines were pre-embedded, and the upper rebars of the floorslab were bound. Slab joint formwork was constructed in the morning, and concrete pouring was performed in the afternoon.

Structural analysis of single-layer installation: Wallboards were installed, 14.4 min/board, i.e. 50 each day (12 h). Wallboards of one section were installed within one day. After the installation of wallboards of the first stage, operations such as sleeve grouting, binding of post-cast strip rebars, formwork reinforcement and setting of support frame were performed. Moreover the setting of wallboards of the second stage started.

Stairs were hoisted after the hoisting of superposed beams, along with the installation of wallboards of the third stage. Superimposed sheets were divided into two parts. After the installation of the first part, water and electricity pipelines pre-embedding, rebar binding and formwork construction were carried out.

The second part was installed along with concrete pouring.

culation and compared. Table 4 and 5 show the detailed costs.

3.2 Comparison of construction cost

The construction cost data of the prefabricated and cast-in-place engineering were obtained through cal-

Table 4 – Cost comparison of the cast-in-place and prefabricated shear wall structures (civil engineering part)

Name	Cast-in-place shear wall structure	Prefabricated shear wall structure	(Prefabricated shear wall - cast-in-place shear wall/cast-in-place shear wall)
Total cost (yuan)	14236188.58	17877577.87	25.58%
Cost per unit building area (yuan/m ²)	1289.23	1616.94	25.42%
Item cost in the branch sub-item resilience detailed list (yuan)	10311598.48	14310744.13	38.78%
Measure expense (yuan)	2457440.35	1362355.72	-44.56%
Fee (yuan)	1321456.75	1339990.88	1.40%
Tax (yuan)	478800.54	582711.07	21.70%

Table 5 – Item cost in the branch sub-item resilience detailed list (details)

Name	Cost of labor (yuan)	Material expense (yuan)	Machinery cost (yuan)	Management cost (yuan)	Profit (yuan)
Prefabricated shear wall structure	1409999.5	12061686.88	102876.08	463000.63	288133.7
Cast-in-place shear wall	2231700.51	7222752.7	83425.51	479365.19	298561.5
(Prefabricated shear wall - cast-in-place shear wall)/ cast-in-place shear wall	-36.82%	67.00%	23.31%	-3.41%	-3.49%

Table 4 and 5 demonstrate that the cost per unit building area of the prefabricated shear wall was 25.42% higher than that of the cast-in-place shear wall. It was because that the prefabricated component industry is not developed enough in China, and the prices of the prefabricated components are high in the construction market.

The cost of labor of the prefabricated shear wall was 36.82% lower than that of the cast-in-place shear wall. Workers were needed in the every stage of the cast-in-place construction engineering; but in the prefabricated engineering, workers were greatly needed in the bulk production of the prefabricated components, and the cost of labor in that section was included in the material expense.

The proportion of material expense of the prefabricated shear wall was 67.00% higher than that of the cast-in-place shear wall. It was because large-scale production cannot be realized because of the non-standard production flow of the prefabricated components.

Machinery cost occupied a small proportion in the costs of the two construction modes, but the machinery cost of the prefabricated shear wall was 23.31% higher than that of the cast-in-place shear wall. It was because that more mechanical equip-

ment was used in the prefabricated construction. The proportion of the measure expense in the total cost decreased from 17.26% to 7.62%, and the measure expense of the prefabricated shear wall structure was 44.56% lower than that of the cast-in-place shear wall structure. The prefabricated components could be used as floor and formwork, which greatly reduced the application of formwork and scaffold.

The above analysis suggested that the prefabricated building was more economical and resource-saving.

3.3 Analysis of the sub-items

There was a difference between the civil engineering costs of the prefabricated and cast-in-place buildings, and the difference of the total cost mainly reflected on the sub-items (Table 6).

Table 6 The civil engineering costs of the prefabricated and cast-in-place building.

	Cost of the prefabricated building (yuan/m ²)	Cost of the cast-in-place building (yuan/m ²)
Masonry engineering	0.82	20.14
Roofing and waterproof engineering	24.6	60.21

Heat insulation engineering	30.11	96.5
Flooring engineering	10	62.14
Plastering engineering	54.17	97.85

The prefabricated building was mainly composed of the prefabricated components such as precast beams, precast columns and precast slab. The cost of the prefabricated building was higher than that of the traditional cast-in-place building because of the high price of the prefabricated building materials and professional installation technologies. But the costs of earthwork and foundation of the prefabricated building were lower.

(1) Masonry engineering: Bricks and thistle boards were the major construction materials used in the traditional cast-in-place building, while the existence of the prefabricated components greatly reduced the work of masonry engineering in the prefabricated building. The cost of masonry engineering of the prefabricated building and traditional cast-in-place building was 0.82 yuan/m² and 19.32 yuan/m² respectively.

(2) Roofing and waterproof engineering: The superimposed sheets used in the roofing and waterproof engineering of the prefabricated building were prefabricated, which had better water and moisture resistance performance compared to the cast-in-place building. The cost of roofing and waterproof engineering of the prefabricated building and traditional cast-in-place building was 24.6 yuan/m² and 60.21 yuan/m² respectively, i.e., the prefabricated building could save 35.61 yuan/m².

(3) Heat insulation engineering: The heat insulation materials were installed on the external side of the outer walls of the cast-in-place building and in the middle of the outer walls of the prefabricated building, i.e. laminboard. As to the cost, the cost of heat insulation engineering of the prefabricated building and traditional cast-in-place building was 30.11 yuan/m² and 96.5 yuan/m² respectively.

(4) Flooring engineering: Prefabricated slab and cast-in-place laminated layer were used together in the construction of flooring. The cast-in-place laminated layer was covered with pipeline rebars, and the prefabricated slab which was used as floor and permanent formwork reduced cost of formwork. The cost of flooring engineering of the prefabricated building and traditional cast-in-place building was 10 yuan/m² and 62.14 yuan/m² respectively, indicating a large difference of 52.14 yuan/m².

(5) Plastering engineering: The surface of the prefabricated components has been processed in the process of production. Therefore screed-coat was not needed in plastering engineering. The cost of the plastering engineering of the prefabricated building

was lower than that of the traditional cast-in-place building theoretically, about 30% ~ 40% that of the cast-in-place building. But it could be seen from Figure 1 that the cost of plastering engineering was 54.17 yuan/m², which was more than half that of the cast-in-place building (97.85 yuan/m²). It was because that the production of the prefabricated components was not standardized in China, and the construction technology and management level were also not satisfactory.

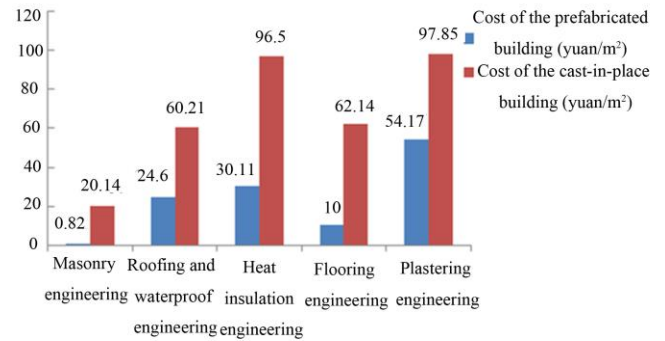


Figure 1 – The histogram of difference of civil engineering cost between the prefabricated and cast-in-place engineering.

3.4 Measures for reducing cost

3.4.1 Optimizing process control

(1) Optimizing design: the design of architectural drawing is indispensable in the management of project cost. Every links of a project should be fully considered in the planning stage, and relevant technical schemes, especially about the prefabricated components, can be formulated based on the influence of design scheme on the project. Structure which is easy to be manufactured and installation should be preferred.

(2) Simplifying production process: Construction process which involved less procedure should be preferred. Moreover disposable moulds can be replaced with reusable moulds. The prefabricated components can be produced by means of flow line, which can improve production efficiency and reduce cost.

(3) Optimizing technical route and installation scheme: One component can be produced in different ways. Different production methods will lead to different technical routes and installation methods. Therefore reasonable production method, technical route and installation method should be selected for the production of the components.

3.4.2 Playing the decisive role of the government

The effective and reasonable management of the government plays a key role in reducing the civil engineering cost of prefabricated buildings. The government can provide indirect support for the devel-

opment of prefabricated buildings by attracting foreign investment with relevant policies and direct support by macroscopically adjusting the construction market, take efforts to publicize the advantages of prefabricated buildings and indirectly reduce construction cost by reforming the current categories of taxes of prefabricated component producers. Moreover it can strengthen the qualification management of prefabricated components enterprises and positively combine the advanced and perfect construction technologies and management system in foreign countries with the characteristics of prefabricated building in China.

3.4.3 Building information modeling based cost management and control

Plenty of time can be saved in cost budgeting under the assistance of BIM. In the step of design alteration, construction cost information in the automatic updating market of BIM can greatly reduce the links which need labor. For the construction industry in China, prefabricated building technology has great promoting effect. Moreover putting forward BIM standards and engineering budget software which are suitable for the conditions of China is of great significance to prefabricated building technology.

4 DISCUSSION

With the development of the society, urban construction has tended to develop more rapidly. In the field of construction, the design of the key links of sustainable development should follow the principles of effective utilization of buildings and small damages to environment [11]. Prefabricated building which has advantages of favorable construction environment, few construction wastes and low construction cost have emerged. But prefabricated building technology in China is not advanced enough in aspects of experience and skills compared to the developed countries [14]. In the developed countries, there are many reasons for the success of prefabricated building; the primary one is demand, and the other reasons are the benefits brought by factory manufacturing such as energy efficiency, installation speed and low cost [9].

Low construction cost is an advantage of prefabricated building. BIM as an important component of production, implementation and the development of prefabricated building board can reduce a large amount of construction wastes [5] and is beneficial to the recycling of construction wastes [6]. Moreover the three-dimensional model of a building can be constructed intuitively using the virtual reality technology of building information modeling [10]. The combination of self-adaption three-dimensional im-

aging and dimensional mode analysis method can realize detailed and frequent analysis of prefabricated components [12], which can reduce cost in the design stage. Multi-functional construction platform as a building elevation construction device can reduce labor intensity, improve labor productivity, ensure safety construction, and shorten the duration of construction [15].

In this paper, the flow of different construction stages of prefabricated building was analyzed, and the factors influencing the cost of different construction stages including the normativity of the design technical specification, the reasonability of the design drawings, the selection of production method and the production of prefabricated components in the production stage, the number and shape of prefabricated components, the conditions of transport route, freight volume, the truck loading direction of components, transportation safety and storage location in the stage of transportation and different construction methods and technical routes in the stage of construction and installation were explored.

5 CONCLUSION

The costs in different construction flows were compared between the prefabricated building and the traditional concrete building taking a real engineering case as an example. The results demonstrated that the cost of the prefabricated building was much lower than that of the traditional concrete building. Moreover several effective measures for controlling construction cost were put forward. The first measure is to optimize process control including optimizing the design of construction drawing, simplifying production process and optimizing technical routes and installation schemes. The second measure is to play the decisive role of the government including macroscopically adjusting the construction market with relevant supportive policies, formulating policies to attract foreign investment and reforming the categories of taxes of the prefabricated components. The third measure is to strictly review prefabricated component producers. The last measure is to make construction budget with building information modeling and optimize BIM technology. The above measures can provide a reference for similar projects.

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