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Capital Cost Optimization for Prefabrication: A Factor Analysis Evaluation Model

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Abstract: High capital cost is a significant hindrance to the promotion of prefabrication. In order to optimize cost management and reduce capital cost, this study aims to explore the latent factors and factor analysis evaluation model. Semi-structured interviews were conducted to explore potential variables and then questionnaire survey was employed to collect professionals' views on their effects. After data collection, exploratory factor analysis was adopted to explore the latent factors. Seven latent factors were identified, including "Management Index", "Construction Dissipation Index", "Productivity Index", "Design Efficiency Index", "Transport Dissipation Index", "Material increment Index" and "Depreciation amortization Index". With these latent factors, a factor analysis evaluation model (FAEM), divided into factor analysis model (FAM) and comprehensive evaluation model (CEM), was established. The FAM was used to explore the effect of observed variables on the high capital cost of prefabrication, while the CEM was used to evaluate comprehensive cost management level on prefabrication projects. Case studies were conducted to verify the models. The results revealed that collaborative management had a positive effect on capital cost of prefabrication. Material increment costs and labor costs had significant impacts on production cost. This study demonstrated the potential of on-site management and standardization design to reduce capital cost. Hence, collaborative management is necessary for cost management of prefabrication. Innovation and detailed design were needed to improve cost performance. The new form of precast component factories can be explored to reduce transportation cost. Meanwhile, targeted strategies can be adopted for different prefabrication projects. The findings optimized the capital cost and improved the cost performance through providing an evaluation and optimization model, which helps managers to evaluate cost management level of prefabrication and explore key inducers for high capital cost.

Keywords: construction management; sustainability; cost optimization; factor analysis evaluation model; prefabrication

1. Introduction

Environmental pollution has got great attentions from the construction industry [1–4]. Prefabrication, as a form of environmental and sustainable off-site construction, has become popular in many nations [5,6]. "Prefabrication" is the process of manufacturing and assembling the major building components at a remote factory, transport to on site and then installation into a building (Modular Building Institute) [7]. The advantages of prefabrication include but are not limited to: reduction in waste, time, life-cycle cost, risk and pollution. As a green, environment-friendly and sustainable construction methods, prefabrication has drawn more attention from the government and enterprises [8,9].

However, the adoption of prefabrication has been hindered by some factors. Technical risk reduced the enthusiasm of some enterprises [10] but technical risk has been gradually resolved in recent years due to technological innovation and technological improvement. However, high capital cost was still an important hindrance to prefabrication development [11]. Stakeholders pursue the benefits and profits and take sunk cost risk into account when they adopt the new technologies [12]. However, the benefits of prefabrication tend to be environmental, ecological and social benefits, as well as economic benefits of the whole life cycle (WLC) [13]. Developers, contractors and other stakeholders have paid more attention to the direct economic benefits of prefabrication [14]. High capital cost is likely to reduce the direct economic benefits to be received by these stakeholders [11], thus becoming a significant barrier to prefabrication development.

Meanwhile, the traditional on-site construction method has become more mature in terms of technological innovation and management mode [15–18]. Improvement has been reported in reducing environmental pollution and safety accidents, by using alufer templates instead of wooden templates to protect the environment, lowering safety and civilized costs to reduce pollution and accident probability while increasing safety training for construction workers. Additionally, the capital cost of traditional on-site construction was 10–20% lower than that of prefabrication [11]. The lower capital cost of traditional on-site construction has been favored by the stakeholders. Hence, capital cost become the most important factor for clients' consideration when they select construction methods. 85% of the clients refuse to choose prefabrication due to the high capital cost [19]. In addition, many stakeholders are willing to adopt prefabrication because of the corporate social responsibility (CSR) but not the direct economic interests. The CSR could contribute to indirect economic performance by building corporate loyalty, brand and engagement [20,21]. Meanwhile, financial incentives policies (FI) was another important driver for stakeholders to adopt prefabrication [11,12,22,23], including incentive policies and mandatory policies, such as construction area reduction, financial subsidy and tax allowance, land ratification policy, bidding conditions limitation, etc. However, CSR and FI were temporary drivers for prefabrication development, while economic benefits and cost performance have been seen as the sustainable drivers for promoting prefabrication. Hence, reduction in capital cost become the primary tasks for promoting prefabrication.

2. Literature Review

2.1. Cost Analysis

Previous studies on prefabrication cost have contributed greatly to prefabrication development. High capital cost was the most important barrier to adopting prefabrication [10–12]. Mao et al. defined the components of the WLC of prefabrication, including preliminary cost, capital cost, facility management cost and disposal cost [11]. Li et al. found that stakeholders usually focused on the capital cost, especially design cost, prefabricated cost and construction cost [12]. Comparison between prefabrication and traditional on-site construction has also been made in previous research. The analysis results of comparison were divided into two distinct directions: (1) higher capital cost of prefabrication and (2) lower cost of prefabrication. Mao et al. found the increase in the total construction cost of prefabrication ranged from 318 yuan/m^2 (27%) to 1263 yuan/m^2 (109%) in different projects [11]. Chen et al. revealed that initial construction cost was 10–20% higher than on-site construction cost [24]. Jaillon et al. investigated construction costs for prefabrication and found that they were slightly higher (on average 1.4%) than the cost of traditional on-site methods in Hong Kong [8]. However, cost-effectiveness of prefabrication was identified in other studies. Kadir et al. found the usage of workers decreased by 15–20% and the use of foreign workers decreased by 30% in areas that used machinery and electrical equipment [25]. Pan et al. suggested that average reduction in construction time and labor was about 15% and 16%, respectively; average accident rate reduced to 22.3 per 1000 workers; and construction waste also reduced by about 65% [19]. Chen et al. found that plastering, timber formwork and concrete works were saved by about 100%, 74–87% and 51–60%, respectively: 55% for the concrete quantities, 40% for the reinforcing steel and 70% for timber formwork [24]. Jaillon et al. revealed that construction time, construction waste and labor requirement on-site reduced by 20%, 56% and 9.5%, respectively [8]. Meanwhile, Vivian et al. indicated 30% reduction in site manpower in prefabrication [26]. Cost analysis were divergent in previous studies. Some studies revealed that capital cost of prefabrication was higher than that of traditional on-site construction. Others found that prefabrication benefited from the whole life cycle costs (WLCC). However, the previous studies ignored the latent factors affecting high capital cost of prefabrication at the category and elements levels.

2.2. Cost Increments

Cost increments were also explored in previous studies. Pan et al. suggested that using well-proven methods and materials were the contributors to the high capital cost [27]. The construction system also influences high cost of prefabrication. The cost of reinforced concrete frame or steel frame was 11–32% higher than cross-wall in the prefabrication projects [28]. Mao et al. proposed that some unknown techniques contributed to the high capital cost, which decreased construction costs but increased effectiveness [11]. Design diversity, aesthetics, maintenance complexity and quality impression also affect the initial cost [12,29,30]. Meanwhile, supply chain issues and lack of codes and standards contributed to high cost [10,12,29]. Chua et al. revealed the cost of mold usage and replacement had an impact on prefabrication cost [31]. Alireza et al. estimated that the transportation of precast component (PC) materials accounted for 10–20% of the total project expenditure [32]. Chen et al. [24] proposed that construction methods affected the long-term cost, such as durability, maintenance cost and the whole life cycle costs (WLCC). Also, capacity of professional workers of on-site and off-site has an impact on the cost as high labor costs [29]. As for machines, the larger lifting weight of tower crane on-site was usually acquired by the larger dimensions of PC, thus resulting in high mechanical cost [11]. Moreover, the special construction technology was added to prefabrication, such as steam curing and storage of PC, which increased the production cost of PC [29]. The deepening design cost was also increased in the prefabrication method due to the separation between the design and production processes. Previous studies have explored some aspects of the variables that affect the high capital cost of prefabrication but there has been no systematic research into those variables and no exploration of the significance of those variables. Otherwise, where do the cost increments occur in the project and what catalogue can be optimized for reducing the capital cost still need exploration.

2.3. Strategy for Cost Performance

Strategies have been adopted to reduce high cost and improve cost performance. James et al. explored the relationship between standardization and modular industrial plants and probed the characteristics of modular standardized plants for improving the cost performance [33]. Perera et al. found a way to reduce the WLCC by component standardization. Reduction in PC diversity brought about some benefits, such as reduction of requirement of multi-skills in the workers and increasing the production volume [34]. Additionally, Arashpour et al. asserted that the cost can be optimized by process integration and multi-skilled resource utilization [35]. Seong et al. suggested that reducing total supply chain costs requires an understanding of where the costs occur and how each activity impacts the total supply chain costs before finding a solution to cost problems [36]. Jaillon et al. considered the economies of scale as a critical factor for prefabrication [37]. Mass production of building components can reduce construction cost effectively. Vivian et al. developed several tactics to effectively reduce construction cost effectively, including usage of recycle materials for the PC and standardized design layouts [38]. Ahmadian et al. optimized the transportation process to reduce the cost of PC by categorizing construction materials [32]. Khalili et al. found that prefabrication configuration and component grouping in production planning for prefabricated structures can reduce total costs by up to 13%, compared to the existing planning approach [31]. Pan et al. found that developing and innovating cross-wall technology led to sustained cost savings up to 25% [39]. Meanwhile, integrating design and construction processes [40], supply chain management and learning to fully assure the benefits of off-site technologies were important factors for cost performance [41]. Additionally, Chen et al. also explored the criteria for selecting the construction method [24]. Pan et al. established and weighted decision criteria for building system selection in order to promote sustainable construction [39]. These criteria help stakeholders to select the appropriate construction method between prefabrication or traditional on-site construction. Previous studies have explored some strategies for cost performance but few studies have been designed for reducing high capital cost of prefabrication. Hence, further research needs to be conducted for evaluation the validity of those strategies for prefabrication.

Although there have been an increasing number of relevant researches on prefabrication cost in recent years, the research focused on the capital cost of prefabrication is still limited, especially at the category and elements levels. What are the latent factors affecting the capital cost of prefabrication? How to evaluate the cost management of prefabrication comprehensively? Where do the cost increments occur? How does each factor affect the capital cost? What catalogue can be optimized? How to improve the cost performance of prefabrication? To answer these questions, this study aims to optimize the high capital cost of prefabrication. Its specific objectives are to: (i) explore the latent factors affecting the high capital cost; (ii) evaluate the cost management level comprehensively; (iii) explore the inducers and their impacts; and (iv) optimize the cost catalogue to improve cost performance.

As a starting point, we seek latent factors affecting the high capital cost of prefabrication. Afterwards, there is a section on "Research methodology", including capital cost analysis of prefabrication, variables determination, exploratory factor analysis and detailed cases study, followed by "Results" on "Case evaluation", "Case analysis" and "Case comparison". Finally, a "Discussion" section is presented and followed by "Conclusions".

3. Research Methodology

Similar terms of prefabrication can be found in research: such as industrialized building (Malaysia), prefabricated building, preassembly, modularization and off-site fabrication (USA), mass production, modern method of construction and off-site construction (UK, Japan and Singapore) [5,9,28,38]. Similar to traditional on-site construction, prefabrication can be used to form a variety of architectures and functions, including residential, commercial buildings and infrastructure [11]. The facility management cost (FMC), disposal cost and the whole life cost (WLC) may be lower in prefabrication but the capital cost tends to be higher [11,37]. However, stakeholders paid more attention to capital cost for pursuing economic benefits [19,42]. Hence, optimization capital cost of prefabrication was the primary task for prefabrication development.

3.1. Capital Cost of Prefabrication

Capital costs are the total costs including bring a project to a commercially operable status [11]. However, the definition of capital cost for prefabrication was vague. The process of prefabrication was usually divided into three parts: design, PC production, including off-site production and transportation, on-site installation [43]. To perform a more accurate and reasonable analysis of the capital cost increment, this study ignored the items that are not different between traditional on-site construction and prefabrication, such as inflation, land acquisition cost, commission and hand-over cost, capital management cost and capital overheads [29]. Hence, the crucial capital cost of prefabrication (C) consists of the design cost (Cd), the production cost (Cp)—which includes the precast component cost (Cpc) and transportation costs (Ct)—and on-site installation costs (Ci) (Equation (1)) at the category level. Bill-of-Quantity (BOQ) model is an international valuation criterion, which can trace back to 1930s in the UK (Royal Institution of Chartered Surveyor). The BOQ valuation model mainly consists of BOQ and comprehensive unit price (CUP). The BOQ is usually offered by the tenderer, which is used to measure the entity and disposal consumption. While the CUP is determined by the bidder. The BOQ model has been widely used in some developed nations, such as USA, UK, Switzerland and China etc. Under the BOQ model, the capital cost is divided into labor cost, materials cost, machinery cost, management fees, profits and risk cost at the element level. Difference from the traditional on-site construction, the prefabrication capital cost has a certain deviation in the component elements. Cd mainly includes labor cost. Cp includes the main material costs (Cmm), auxiliary material costs (Cam), labor costs (Cl), other costs of production (Cop), management fees for production (Mf), profit for production (P), taxation expenses (T) and depreciation expenses (Cde) (Equation (2)). Ci includes labor costs for installation (Cli), material costs of embedded parts (Cme), installation machinery costs on-site (Cmi) and other costs of installation (Coi). (Equation (3)).

$$\mathrm{C} = \mathrm{Cd} + \mathrm{Cp} + \mathrm{Ci} + \mathrm{U} \tag{1}$$

$$\mathrm{Cp} = \mathrm{Cmm} + \mathrm{Cam} + \mathrm{Cl} + \mathrm{Cop} + \mathrm{Mf} + \mathrm{P} + \mathrm{T} + \mathrm{Cde} + \mathrm{Up} \tag{2}$$

$$\mathrm{Ci} = \mathrm{Cli} + \mathrm{Cme} + \mathrm{Cmi} + \mathrm{Coi} + \mathrm{Uc} \tag{3}$$

where U represents the risk of cost deviations in prefabrication projects; Up represents the risk of cost deviations in the production and transportation stages; and Uc represents the risk of cost deviations in the installation stages.

3.2. Research Instrument

Exploratory factor analysis (EFA) has been recognized as a successful tool of dimensionality reduction and classification by detecting relationships among variables [44–46]. EFA has been widely used to integrate a large number of observed variables x into a few common latent factor f [47]. This technique has been applied in the field of management and economics, as well as construction project management [48]. Statistics used in EFA include communality, variance, factor loading, etc. The communality represents the effect of all common factors f on the i_{th} observed variables x_i. The larger the communality is, the greater the dependence of x_i on f is. Variance represents the effect of the j_{th} common factor f_j on the i_{th} observed variables x_i. The larger the variance is, the greater effect of f_j on i_{th} is. Factor loading a_{ij} represents the dependence of x_i on the f_j. The larger the factor loading is, the greater dependence of i_{th} on f_j is. EFA was usually used for comprehensive evaluation, ranking and estimating the merits of the objects to be evaluated. In addition, EFA can be used to evaluate the advantages and disadvantages of the objects, adopt the strengths while overcoming the weaknesses and then improve the comprehensive level of the objects [49,50].

EFA has been used to identify and evaluate the factors delaying public–private partnership projects development [44], assess the barriers to bond financing in infrastructure projects [48], identify the important aspects of the evaluation process and factors in the ex post evaluation [51] and measure the lifecycle performance of project [52]. Whang et al. used EFA to identify and rank the critical design management factors for high-rise building projects, which provided appropriate decision-making support for contractors [16]. EFA was also used to identify the design risk factors in design-build projects and analyze their impacts on project performance [52]. Additionally, Park et al. identified critical success factors for effective stakeholder management and screened systematic and strategic approaches to stakeholder management [42]. Martens et al. used EFA to explore the key aspects of sustainability in the context of project management to gain an understanding of the importance of sustainability [53]. In sum, EFA has been widely used in construction project management and has brought benefits to project performance.

Figure 1 shows the methodology adopted for the analysis in this study. In the first step, the high capital cost was the most important hindrance to prefabrication development. This material was collected from content analysis and semi-structured interviews. Then, this study identifies the critical variables affecting the high capital cost. Third, a questionnaire survey was designed, distributed and collected. A pilot survey was conducted with the experts experienced in prefabrication project management before the finalized questionnaires were distributed. In the fourth step, EFA was conducted to explore the latent factors affecting the high capital cost. Then, factor analysis evaluation model (FAEM) was developed for further study, including the factor analysis model (FAM) and comprehensive evaluation model (CEM). FAM can be used to identify specific observed variables affecting the high capital cost, thus adopting the strengths, overcoming the weaknesses and improving the comprehensive competitiveness. CEM can be used to evaluate the comprehensive management level of projects. Lastly, a case study was conducted to validate the FAEM. The validation results have been confirmed by the experts from five prefabrication projects.

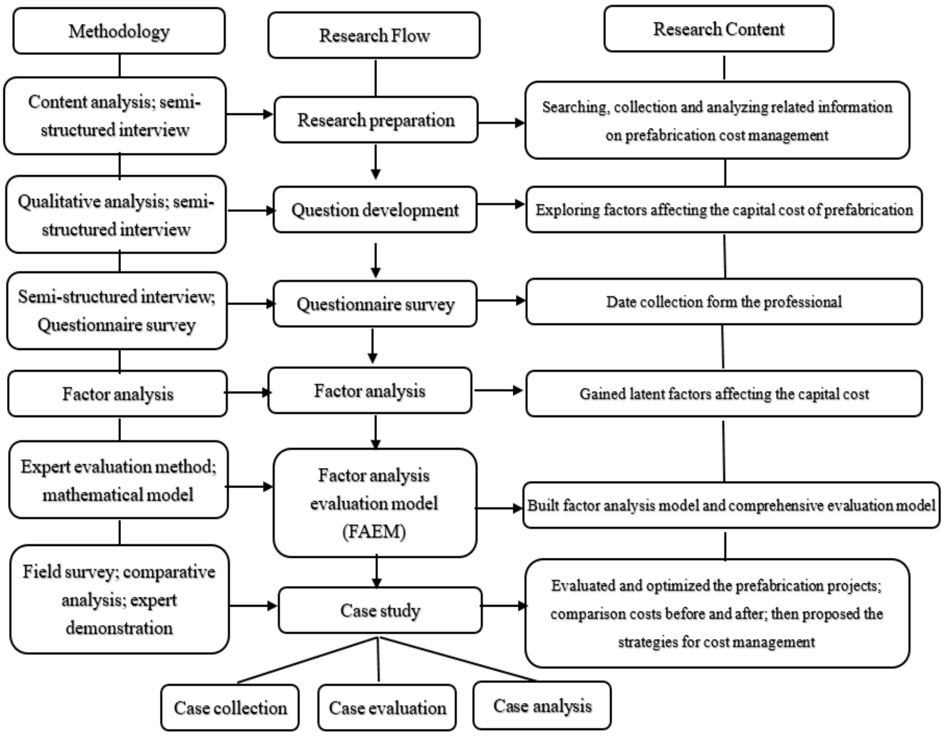

Figure 1. Research methodology.

3.3. Factors Affecting the High Capital Cost

3.3.1. Semi-Structured Interview

Based on the variables identified from literature review, semi-structured interviews were conducted [54–56]. A total of 11 professionals experienced in prefabrication project management were interviewed. The experts were asked to identify the variables affecting the high capital cost, including 3 experts from clients, 2 designers, 1 supervisor, 2 contractors, 2 PC manufactures and 1 professor. The experts confirmed the validity of variables identified from literature review. Then, they replenished the potential variables for further study. Each interview lasted 30–90 min. The interviews began in October 2016 and ended in November 2017. This research identified a total of 49 variables (Table 1).

Table 1. Variables affecting the high capital cost of prefabrication.

Code	Variables	Sources
FD1	Coordination between the designers and clients	[57–60]
FD2	Coordination between the designers and PC manufacturers	[57–59]
FD3	Coordination between the designers and contractors	[57,58,61]
FD4	Specification and Standards for prefabrication design	[34,62]

Table 1. *Cont.*

Code	Variables	Sources
FD5	Standard component catalogue of prefabrication	[34,62]
FD6	Design pattern of prefabrication	[34,63]
FD7	Diversity of prefabrication structure	[32]
FD8	Related experience of the designers	[63]
FD9	Collaborative capacity among professional designers	[57,58,64]
FD10	Design level of teamwork	[63]
FD11	Rationality of precast component split	[11,28]
FD12	Node coordination between precast components and on-site components	[65]
FD13	Coordination of connection nodes of precast components	[43]
FD14	Reuse ratio of standard precast components	[11]
FD15	Type of building structure	[28]
FD16	Third party of drawing audit organization	interviews
FPT1	Specification and Standards for precast component production	[28]
FPT2	Design plan for precast component production line	interviews
FPT3	Order quantity of precast component	[66]
FPT4	Capacity of production line in precast component	interviews
FPT5	Depreciation of fixed assets	interviews
FPT6	Maintenance of mechanical installation	[43]
FPT7	Production technology of precast component	[67]
FPT8	Technical standards system of prefabrication	[67]
FPT9	Attrition rate of reinforcement	[68]
FPT10	Additional reinforcement due to connection points	interviews
FPT11	Curing condition to precast component	interviews
FPT12	Reuse ratio of precast component mold	[11]
FPT13	Types and specifications in precast component mold	[11]
FPT14	Scrap quantity of mold	[11]
FPT15	Number of professionals	interviews
FPT16	Efficiency of production worker	[66,69]
FPT17	Turnover rate of production worker	interviews
FPT18	Training cost of production workers	interviews
FPT19	Storage cost of precast component in factory	interviews
FPT20	Transport machinery	[65]
FPT21	Transportation and shipment forms	[70]
FPT22	Transport distance	[70]
FPT23	Attrition rate of precast component in transportation	[11]
FC1	Related experience of manager	[71,72]
FC2	Coordination of all types of work on site	[68]
FC3	Operant level on installation personnel	interviews
FC4	Technical specifications and standards for installation	[73]
FC5	Storage condition of precast component on-site	interviews
FC6	Mechanical efficiency of tower crane	[30,66]
FC7	Hoisting procedure of precast component	[68]
FC8	Redundancy of installation process	[68]
FC9	The scale of prefabrication project	[28,74]
FC10	Rental fee of installation equipment	interviews

3.3.2. Descriptive Statistics

A questionnaire was designed to collect professionals' views on the effects of the variables on capital cost. The five-point Likert scale was used to indicate the significance of variables, in which "1" represents "negligible" and "5" means "most important" [29]. The questionnaire has been tested through a pilot study. The questionnaire was then distributed throughout multiple channels including during the field investigations, by e-mail and online (Sojump). The survey was conducted from 15 December 2016 to 5 May 2017. Then, 389 questionnaires were distributed and 191 responses were returned, with a response rate of 49.1%, which was high compared to studies using questionnaire surveys [75]. In this study, the authors limited the scope to the respondents who were experienced in both on—site construction and prefabrication project management and took over 5 years on project management. To ensure the quality and validity of questionnaire, the authors screened and eliminated some questionnaires. A total of 128 respondents were obtained and efficiency rate was 67%.

SPSS (Statistical Product and Service Solutions) 22.0 software (IBM SPSS Company, Chicago, IL, USA) was used to test the validity of the questionnaire [43,61]. The coefficient of Cronbach's α is an important index to judge the reliability of the data from the questionnaire [43]. In this survey, α was 0.936, representing the validity and reliability of the questionnaire results.

3.3.3. Data Pretreatment

EFA reduces the dimension of the variables identified in Table 1 to obtain a smaller number of underlying latent factors [48], which can explain. most of the observed variables [15,76]. Variable correlation is the precondition of the EFA. To validate the correlativity, two tests on the sampling adequacy were performed: the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity. The KMO test was conducted to confirm the correlation of variables through correlation coefficient and partial correlation coefficient. The larger the value, the closer the variables. Meanwhile, the Bartlett's test was conducted to test whether variables are relevant. When the probability is less than the given one, it proves that variables are not independent [51,77]. The KMO compares the magnitude of the squared correlation between variables to the squared partial correlation between variables. The following outcomes are commonly accepted for the value of KMO > 0.9—Excellent, KMO > 0.8—Good, KMO > 0.7—Acceptable, KMO > 0.6—Questionable and KMO < 0.5—Unacceptable [15]. Bartlett's test examines whether or not the correlation coefficient matrix of the variables is an identity matrix with the correlation coefficients outside the primary diagonal close to zero [44]. The result showed that KMO was 0.743 with a significance (Sig.) of 0.000, suggesting that the data were appropriate for EFA.

To ensure the rationality of EFA, this study ignored the variables with communalities below 0.3, or variances below 0.4 [42,77]. Meanwhile, the authors also retained the variables through the discussion with the experts. EFA needs to be done again once a variable was deleted. Finally, the variables were identified and used in next step (Table 2).

Table 2. Variables affecting the high capital cost of prefabrication-selected.

Code	Variables
FD2	Coordination between designer and PC manufacturer
FD5	Standard component catalogue of prefabricated building
FD6	Design pattern of prefabricated building
FD7	Diversity of prefabricated building structure
FD8	Related experience of designer
FD9	Collaborative capacity among professional designers
FD10	Design level of teamwork
FPT1	Specification and Standards for PC production
FPT2	Design plan for PC production line
FPT5	Depreciation of fixed assets
FPT6	Maintenance of mechanical installation
FPT8	Technical standards system of prefabricated building
FPT9	Attrition rate of reinforcement
FPT10	Additional reinforcement due to connection points
FPT15	Number of professionals
FPT16	Efficiency of production worker
FPT18	Training cost of production workers
FPT19	Storage cost of PC in precast plant
FPT20	Selection of transport machinery used for PC
FPT21	Transportation and shipment forms of PC
FPT23	Attrition rate of PC component in transportation
FC1	Related experience of manager
FC2	Coordination of all types of work on site
FC5	Storage condition of PC on-site
FC6	Mechanical efficiency of tower crane
FC7	Hoisting procedure of PC

3.4. Exploratory Factor Analysis

EFA was performed on the data set to extract the latent factors underlying a large number of variables [44,78]. Principal component analysis (PCA) is the most extensively used method and was used in this case [79]. Table 3 revealed that the communalities of the variables reached 65% except FC6 (60.2%). The results reported that nearly 65% of each index be explained by the latent factors retained.

Table 3. Communalities.

Code	Initial	Extraction
FD2	1.000	0.750
FD5	1.000	0.686
FD6	1.000	0.790
FD7	1.000	0.710
FD8	1.000	0.828
FD9	1.000	0.742
FD10	1.000	0.696
FPT1	1.000	0.658
FPT2	1.000	0.728
FPT5	1.000	0.775
FPT6	1.000	0.842
FPT8	1.000	0.788
FPT9	1.000	0.836
FPT10	1.000	0.809
FPT15	1.000	0.665
FPT16	1.000	0.691
FPT18	1.000	0.651
FPT19	1.000	0.715
FPT20	1.000	0.698
FPT21	1.000	0.693
FPT23	1.000	0.767
FC1	1.000	0.817
FC2	1.000	0.783
FC5	1.000	0.697
FC6	1.000	0.602
FC7	1.000	0.718

3.4.1. Extraction of Initial Factors

Communality is used to determine the reasonable number of latent factors to be extracted [48]. PCA was conducted using the SPSS 22.0. The eigenvalues, percentage of variance and total variance of variables were also shown in Table 4. However, the important variables are those whose eigenvalues are greater than or equal to 1, because the eigenvalue can measure how a standard variable contributes to the principal components [79]. A component with an eigenvalue of less than 1 is considered less important and can be ignored. Meanwhile, the total variance % should reach 40% [78]. Furthermore, the slope was taken into account. Hence, 7 latent factors were extracted from the data (Table 4). Cumulative variance reached 73.59%, which showed that those 7 latent factors can explain the important information of the 26 variables. "Extraction Sums of Squared Loadings" showed that cumulative variance was 73.59% when 7 latent factors were retained. As rotated, the cumulative variance still reached 73.59% but the variance of latent factors changed by redistribution to assign the variables for latent factors. Component 1 was the most significant latent factor (14.765%).

Table 4. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.855	30.210	30.210	7.855	30.210	30.210	3.839	14.765	14.765
2	3.518	13.529	43.739	3.518	13.529	43.739	3.559	13.689	28.453
3	2.047	7.873	51.612	2.047	7.873	51.612	2.691	10.351	38.805
4	1.959	7.536	59.148	1.959	7.536	59.148	2.617	10.065	48.869
5	1.588	6.108	65.256	1.588	6.108	65.256	2.246	8.638	57.507
6	1.124	4.323	69.579	1.124	4.323	69.579	2.100	8.079	65.586
7	1.043	4.011	73.590	1.043	4.011	73.590	2.081	8.004	73.590
8	0.939	3.612	77.202						
9	0.817	3.143	80.345						
10	0.763	2.934	83.279						
11	0.569	2.190	85.469						
12	0.508	1.953	87.422						
13	0.437	1.682	89.104						
14	0.425	1.634	90.738						
15	0.360	1.385	92.123						
16	0.348	1.338	93.460						
17	0.317	1.217	94.678						
18	0.252	0.969	95.647						
19	0.227	0.872	96.519						
20	0.194	0.745	97.264						
21	0.173	0.667	97.932						
22	0.154	0.594	98.526						
23	0.122	0.468	98.994						
24	0.103	0.397	99.391						
25	0.097	0.372	99.763						
26	0.062	0.237	100.000						

Extraction Method: Principal Component Analysis.

3.4.2. Varimax Rotation and Interpretation

To attain the latent factors and further nominate, the varimax rotation was performed on the initial PCA results to reveal more interpretable factors. The results of varimax rotation are shown in Table 5. Each factor consisted of the variables with the highest loadings. The factor loading represented the degree to which each variable was associated with its assigned factor [51,78]. To identify the loading factor as a significant, the value of the factor loading should be greater than 0.45 or less than −0.45 [80]. Table 5 exhibits the variables subsequent to grouping of the determinants. For example, FC2, FC1, FD2, FPT16 and FD10 were grouped in latent factor 1 (F1), with the factor loadings of 0.863, 0.862, 0.781, 0.741 and 0.559, respectively.

Table 5. Rotated component matrix.

Code	Component						
	1	2	3	4	5	6	7
FC2	0.863	0.070	0.029	0.105	0.107	−0.078	0.063
FC1	0.862	0.121	0.086	−0.012	−0.035	0.168	−0.147
FD2	0.781	0.017	0.009	0.279	−0.120	0.216	−0.025
FPT16	0.741	0.197	−0.153	0.077	0.110	0.226	0.105
FD10	0.559	0.104	0.343	−0.023	0.238	0.172	0.412
FC6	0.193	0.700	−0.117	0.225	0.074	−0.037	0.055
FPT23	0.189	0.687	0.149	−0.245	0.421	0.000	−0.001
FPT15	0.089	0.674	0.103	0.030	0.009	0.309	0.309
FPT18	0.026	0.667	0.343	0.201	0.007	0.199	0.089
FC7	0.172	0.592	0.224	0.309	0.153	−0.002	0.411
FPT19	−0.017	0.535	0.222	0.209	0.422	0.391	−0.072
FPT20	0.003	0.521	0.506	−0.002	0.412	−0.018	0.000

Table 5. *Cont.*

Code	Component						
	1	2	3	4	5	6	7
FPT2	−0.140	−0.027	0.833	0.018	0.072	−0.087	0.030
FD9	0.164	0.256	0.756	0.021	0.054	0.258	0.087
FPT1	0.079	0.401	0.569	0.233	0.262	0.202	0.068
FD6	−0.086	0.037	−0.019	0.852	−0.193	0.072	0.109
FD5	0.270	0.239	−0.026	0.737	0.020	0.109	0.000
FD7	0.235	0.174	0.280	0.697	0.216	−0.115	0.033
FPT21	−0.006	0.135	0.099	−0.067	0.801	0.117	0.074
FC5	0.113	0.319	0.197	0.116	0.580	0.264	0.351
FPT9	0.189	0.191	0.052	0.037	0.353	0.797	0.007
FPT10	0.440	0.095	0.159	0.072	0.001	0.754	−0.086
FPT8	−0.034	0.290	0.034	0.192	0.295	−0.136	0.748
FD8	0.328	0.026	0.506	0.075	0.028	0.270	0.620
FPT6	0.352	−0.039	0.129	0.442	0.343	0.256	−0.566
FPT5	0.324	−0.392	0.051	0.398	0.355	0.247	−0.410

Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 17 iterations. Loading of FPT5 was greater than −0.45. However, FPT5 should be retained because the depreciation cost is significant, ranging from 100 yuan/m^3 to 190 yuan/m^3. Also, the indicators with low loadings could be retained because of their contributions to content validity [81–83]. Taking content validity into account, the authors retained the FPT5 to reflect the knowledge required for this study. For clarity, the variables grouped into latent factors were provided with the new headings. Under delay factors: Factor 1 (F1) can be regarded as "Management Index (MI)"; Factor 2 (F2) as "Construction Dissipation Index (CDI)"; Factor 3 (F3) as "Productivity Index (PI)"; Factor 4 (F4) as "Design Efficiency Index (DEI)"; Factor 5 (F5) as "Transport Dissipation Index (TDI)"; Factor 6 (F6) as "Material increment Index (MII)"; Factor 7 (F7) as "Depreciation amortization Index (DAI)".

3.4.3. Factor Analysis Evaluation Model

The factor analysis evaluation model (FAEM) was divided into two parts: factor analysis model (FAM) (Equation (4)) and comprehensive evaluation model (CEM) (Equation (5)). FAM was used to identify the specific observed variables affecting the high capital cost to adopt strengths while overcoming weaknesses, thus improving the comprehensive competitiveness. CEM was used to evaluate the comprehensive management level of prefabrication projects.

$$\begin{gathered} X = Af + \varepsilon \\ X = (x1,\ x2, \ldots, xm) \\ f = (f1, f2, \ldots, fn) \\ A = \begin{bmatrix} a11 & \cdots & a1n \\ \vdots & \ddots & \vdots \\ am1 & \cdots & amn \end{bmatrix} \end{gathered} \tag{4}$$

where X represents observed variables; f represents latent factors; A represents matrix of load of factors; ε represents specific factor (the value is 0 if the data were collected reasonably or was standardized); m represents the number of observed variables; n represents the number of latent factors; and a_{ij} represents the load on the j latent factor of the i observed variable.

$$\begin{gathered} E = \frac{1}{z} \sum_{i=1}^{n} b_i f_i \\ z = \sum_{i=1}^{n} fi \end{gathered} \tag{5}$$

where E represents comprehensive evaluation value; b_i represents weighting of i_{th} common factor; n represents the number of latent factors.

3.5. Detailed Case Selection

Five cases were collected from a large Chinese construction firm, which was named as Bache to ensure anonymity. Bache devoted to promoting prefabrication development and explored strategies for cost management. These five cases were the pilot projects in our research program, which was supported by the he Ministry of Housing and Urban-Rural Development of People's Republic of China and Bache. Meanwhile, the five cases were conducted to explore the project management mode of prefabrication in Bache. The authors tracked the five prefabrication projects. The conceptual design consisted of 4 steps: (1) designing interview gauge using 7 latent factors; (2) selecting cases and interviewees; (3) field interviews; and (4) data collection. The interview gauge was designed for managers to evaluate project management job satisfaction: 1 = very dissatisfied, 5 = very satisfied. Five cases were selected in Bache to ensure the preciseness, given the construction period, building year, building attributes and other variables. Then, the potential managers in prefabrication projects were identified, including the project manager, chief engineer, business manager at clients and general contractors in relevant projects; department managers in the cost department and the purchase department of Bache; production managers at manufacturer in relevant projects, who were experienced in prefabrication and have taken five years on project management. The total number of experts was 37 and each case was evaluated by 9 experts. The interviews were conducted from December 2016 to January 2017. The approximate length of each interview was 45–60 min [11,12]. All the interviews were recorded on paper. An arithmetic mean was used to represent the score of each factor (Table 6). Meanwhile, the profiles of the five projects are shown in Tables 7–9, respectively. To protect the privacy and interests of the Bache, all the data were adjusted by multiplying by the same coefficients.

Table 6. Scores of each factor.

Factors	Project 1	Project 2	Project 3	Project 4	Project 5
F1	3	2	3	4	4
F2	2	1	3	3	2
F3	4	4	3	2	2
F4	3	3	2	2	3
F5	4	2	2	4	4
F6	4	3	4	3	4
F7	4	5	2	2	3

Table 7. Information of the five cases.

Projects	Project 1	Project 2	Project 3	Project 4	Project 5
Types	Residential building	Residential building	Residential building	Residential building	Residential building
Location	Shanghai	Jinan	Nanjing	Shenzhen	Shenzhen
Building sq.m. (m^2)	29,726	38,155	31,233	30,138	36,217
Structure system	Frame-shear wall structure	Frame-shear wall structure	Frame-shear wall structure	Frame-shear wall structure	Frame-shear wall structure
Completion date	2016	2016	2016	2016	2016
Housing type	3	3	2	2	2
Height (m)	53.65	52.2	58	55.1	58
No. of stories	18.5	18	20	19	20
Precast level (% by volume)	21%	17%	18%	18%	19%
PC unilateral cost higher than traditional (yuan/m^2)	331	338	306	222	106

Table 7. *Cont.*

Projects	Project 1	Project 2	Project 3	Project 4	Project 5
PC installation cost on-site higher than traditional (yuan/m^2)	131	153	100	150	90
Design cost higher than traditional (yuan/m^2)	20	20	20	15	15
Construction cost higher than traditional (yuan/m^3)	381	467	372	316	213

Table 8. Cost analysis of precast façade component—production cost.

Cost Analysis of Precast Facade Component Production							
Code	**Components**	**Unit**	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
1	Main material	yuan/kg	959	1137	924	924	959
1.1	Rebar	yuan/kg	468	468	445	445	468
1.2	Concrete	yuan/m^3	235	256	223	223	235
1.3	Embedded parts	kg	256	413	256	256	256
2	Auxiliary material	-	568	232	235	235	231
2.1	Insert material	m^2	563	56	59	59	56
2.2	Bonded materials	m^2		169	171	171	169
2.3	Retarder	m^2	6	7	5	5	6
3	Labor	m^3	970	1255	1045	1045	1118
4	Others	-	465	574	561	502	446
4.1	Mold	yuan/kg	265	276	295	236	236
4.2	Steam preservation	m^3	50	85	76	76	52
4.3	Packing & transportation	m^3	150	213	190	190	157
5	Management	yuan	96	448	152	162	110
6	Profits	yuan	75	292	215	229	86
7	Tax	yuan	436	669	492	527	462
8	Depreciation	yuan/m^3	100	0	190	190	100
9	Total cost	-	3715	4605	3829	3815	3512

Table 9. Cost analysis of precast facade component—installation cost.

Cost Analysis of Precast Facade Component							
Code	**Components**	**Unit**	**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
1	Labor cost	yuan/m^2	31	34	36	40	45
2	Material cost	yuan/m^2	20	19	30	32	32
3	Mechanical cost	yuan/m^2	20	16	18	20	21
4	Others cost	-	-	-	-	-	-
5	Total	-	156	233	180	187	133

4. Results

4.1. Case Evaluation

Five projects were evaluated using Equations (4) and (5). Variables and cost performance of five projects were evaluated. Based on the results of evaluation, this study explored and analyzed the inducers of the high capital cost of the five projects (Table 10). Meanwhile, project cost management levels were as follows (Table 11): Project 5, Project 4, Project 1, Project 3, Project 2. The evaluation results were consistent with the actual data of the prefabrication projects and the opinions of the 37 experts.

$$
\begin{gathered}
X = Af + \varepsilon \\
X = (x1,\ x2, \ldots, x26) \\
f = (f1, f2, \ldots, f7) \\
A = \begin{bmatrix} a11 & \cdots & a17 \\ \vdots & \ddots & \vdots \\ a261 & \cdots & a267 \end{bmatrix} \\
x_j = \sum_{i=1}^{7} a_{ji} f_i
\end{gathered}
\tag{6}
$$

For

$$x_1 = \sum_{i=1}^{7} a_{1i} f_i$$

$$x_1 = 0.863f1 + 0.070f2 + 0.029f3 + 0.105f4 + 0.107f5 - 0.078f6 + 0.063f7$$

Solution $x_1 = 3.298$.

Table 10. Scores for variables.

Variables	Code	Project 1	Project 2	Project 3	Project 4	Project 5
x_1	FC2	3.298	2.520	3.122	4.247	4.404
x_2	FC1	3.089	1.851	3.490	4.029	3.967
x_3	FD2	3.661	2.735	3.553	3.869	4.212
x_4	FPT16	4.090	2.719	3.841	4.730	4.898
x_5	FD10	5.137	5.573	4.957	5.477	6.514
x_6	FC6	2.660	1.606	2.889	3.384	2.883
x_7	FPT23	2.763	1.762	3.424	4.306	3.942
x_8	FPT15	4.102	3.845	4.532	4.227	4.313
x_9	FPT18	3.784	3.749	4.497	3.995	4.166
x_{10}	FC7	4.758	5.115	4.701	4.957	5.460
x_{11}	FPT19	4.701	3.671	4.900	5.114	5.751
x_{12}	FPT20	3.224	3.319	3.840	4.179	4.557
x_{13}	FPT2	1.205	3.112	1.891	1.150	2.043
x_{14}	FD9	4.035	4.990	4.885	4.143	5.064
x_{15}	FPT1	4.671	5.001	5.077	4.910	5.842
x_{16}	FD6	2.370	2.721	1.621	1.095	1.879
x_{17}	FD5	3.942	3.252	3.398	3.625	4.226
x_{18}	FD7	3.989	4.105	3.498	4.000	4.937
x_{19}	FPT21	3.342	2.641	2.768	4.147	5.036
x_{20}	FC5	5.571	5.390	5.040	5.852	7.042
x_{21}	FPT9	5.430	4.019	5.277	5.324	6.378
x_{22}	FPT10	4.804	3.660	5.073	4.601	5.405
x_{23}	FPT8	3.705	4.855	2.794	3.452	4.295
x_{24}	FD8	5.294	6.894	5.104	4.711	6.183
x_{25}	FPT6	2.923	1.136	2.794	3.447	4.091
x_{26}	FPT5	2.304	1.052	1.620	2.356	3.388

Evaluation set: 1 = very dissatisfied, 2 = dissatisfied, 3 = medium, 4 = satisfied, 5 = very satisfied.

Scoring set: [1,2) = very dissatisfied, [2,3) = dissatisfied, [3,4) = medium, [4,5) = satisfied, [5,∞) = very satisfied. The score lower than 4 means that the variables should be improved in this project.

$$E = \frac{1}{z} \sum_{i=1}^{7} b_i f_i$$

$$z=\sum_{i=1}^{7}fi$$

For

$$E1=\frac{1}{z}\sum_{i=1}^{7}b_1f_i$$

$$z=\sum_{i=1}^{7}bi=0.736$$

$$E1=\frac{1}{0.736}(0.148f1+0.137f2+0.104f3+0.101f4+0.086f5+0.081f6+0.080f7).$$

Solution $E1 = 2.78$.

Table 11. Comprehensive evaluation for cost management level.

Projects	Project 1	Project 2	Project 3	Pject 4	Project 5
E	2.78	2.67	2.75	2.93	3.36

4.2. Case Analysis

The study revealed that the comprehensive value of the five projects were lower than 4, suggesting that all the projects should be improved in terms of cost management. Table 10 revealed scores of the variables, which indicated those variables should be improved (lower than 4.0). Among all variables, 23% were dissatisfied and only 42% were satisfied in project 1; 38% were dissatisfied and 34% satisfied in project 2; 27% were dissatisfied and 42% were satisfied in project 3; and 12% were dissatisfied and 76% were satisfied in project 5. However, all the projects were lower than 4 (satisfied). Thus, the results indicated that the synergy of element but not cost management, was a simple set [59,61]. This phenomenon was usually explained by "1 + 1 < 2."

4.3. Case Comparison

Based on FAM and CEM, this study explored the variables for the high capital cost of the five projects, then evaluated the cost performance comprehensively. The managers put forward specific strategies to reduce high capital cost, focusing on those variables lower in the degree of satisfaction. The cost performances have been improved and optimized in the second phase of project 1 (Project 1′), second phase of project 2 (Project 2′), third phase of project 3 (Project 3′), 3# of first phase of project 4 (Project 4′) and second phase of project 5 (Project 5′) (Tables 12–14). Meanwhile, the proportion of cost variances was calculated to reveal the validity of the optimization strategies in Tables 13 and 14. These data was collected from the same five projects for the first time but in different construction segments. The new five cases have been optimized in cost management based on FAM and CEM. The interviews were conducted from July 2017 to August 2017. To protect the privacy and interests of the Bache, all the data were also adjusted by multiplied by the same coefficients for the first time but these data concealed some details that the Bache would not like to disclose and this information did not impact the comparison [11,29].

Table 12. Information of the five new cases.

Projects	Project 1′	Project 2′	Project 3′	Project 4′	Project 5′
Types	Residential building	Residential building	Residential building	Residential building	Residential building
Location	Shanghai	Jinan	Nanjing	Shenzhen	Shenzhen
Building sq.m. (m^2)	29,726	38,155	31,233	30,138	36,217

Table 12. *Cont.*

Projects	Project 1′	Project 2′	Project 3′	Project 4′	Project 5′
Structure system	Frame-shear wall structure	Frame-shear wall structure	Frame-shear wall structure	Frame-shear wall structure	Frame-shear wall structure
Completion date	2017	2017	2017	2017	2017
Housing type	3	3	2	2	2
Height (m)	53.65	52.2	58	55.1	58
No. of stories	18.5	18	20	19	20
Precast level (% by volume)	21%	17%	18%	18%	19%
PC unilateral cost higher than traditional (yuan/m^2)	289	315	270	213	96
PC installation cost on-site higher than traditional (yuan/m^2)	104	126	91	129	78
Design cost higher than traditional (yuan/m^2)	15	15	10	10	10
Construction cost higher than traditional (yuan/m^3)	306	337	320	265	187

Table 13. Cost analysis of precast facade component in production cost—optimized.

Code	Components	Unit	Project 1′		Project 2′		Project 3′		Project 4′		Project 5′	
1	Main material	yuan/kg	959	27%	2533	58%	1152	38%	1078	36%	1190	51%
1.1	Rebar	yuan/kg	468	13%	445	10%	468	15%	468	16%	445	19%
2	Auxiliary material	m^2	231	7%	70	2%	119	4%	163	5%	16	1%
3	Labor	m^3	1118	32%	419	10%	450	15%	465	15%	337	15%
4	Others	-	446	13%	369	8%	635	21%	589	20%	526	23%
4.1	Mold	yuan/Kg	236	7%	201	4%	296	10%	265	9%	245	11%
4.2	Steam preservation	m^3	52	1%	50	1%	85	3%	50	2%	70	3%
4.3	Packing & transportation	m^3	157	5%	118	3%	254	8%	274	9%	211	9%
5	Management	yuan	110	3%	455	10%	189	6%	265	5%	104	4%
6	Profits	yuan	86	2%	185	4%	204	7%	163	5%	76	3%
7	Tax	yuan	462	13%	323	7%	160	5%	150	5%	73	3%
8	Depreciation	yuan/m^3	100	3%	0	0%	120	4%	130	4%	0	0%
9	Total cost	-	3512	100%	4352	100%	3028	100%	3003	100%	2320	100%
10	Saved	-	203	5%	253	5%	801	21%	812	21%	1192	34%

Table 14. Cost analysis of precast facade component in installation cost—optimized.

Code	Components	Unit	Project 1		Project 2		Project 3		Project 4		Project 5	
1	Labor cost	yuan/m^2	26	16%	30	12%	33	8%	38	5%	43	4%
2	Material cost	yuan/m^2	20	0%	19	0%	28	7%	26	19%	30	6%
3	Mechanical cost	yuan/m^2	16	20%	15	6%	14	22%	15	25%	12	43%
4	Others cost	-	-		-		-		-		-	
5	Total	-	133	15%	187	20%	165	8%	155	17%	120	10%

5. Discussion

5.1. Effect of Cost Optimization Management on Capital Cost

Our study found that the capital cost performance was improved by a factor analysis evaluation model. The results attributed to analyze the detail cost increments through the FAM and evaluate the capital cost management through CEM. In our study, the capital cost of prefabrication was optimized through the 7 latent factors. The authors analyzed the inducers of the high capital cost through FAM, evaluated the cost management of projects through CEM and put forward specific strategies to reduce high capital cost of five cases. Finally, the capital cost was reduced by 30–135 yuan/m^2. Our study showed that the FAEM is applicable to different prefabrication projects but the efficiency of the model varies. This result may be due to some moderators affecting the efficiency of FAEM, i.e., territoriality, diversity and other characteristics of prefabrication projects.

5.2. Effect of Material Increment Index (MII) on Production Cost

The material increment index has an important effect on production cost. Although previous studies revealed that materials (i.e., plastering, timber formwork and concrete works) were saved in prefabrication mode in some nations [24], our study found material increment still an important factor affecting the high capital cost in China. The timber formwork was saved on-site construction but the streel formwork increased in factories. The results caused by lower turnover ratio of streel formwork. Moreover, our results indicated that the material consumption, especially the increase in reinforcement ratio and attrition rate of rebar were important contributors to high material cost. In addition, the results implied that the auxiliary material had an important impact on production cost. This result was possibly attributed to the fact that the auxiliary material was used for face brick, such as insert material and bonded materials and that the cost of auxiliary material was nearly 230 yuan/m^2. Hence, our studies suggested that enhancing the efficiency of auxiliary materials was an effective way to reduce production cost, such as innovation or succedaneum for insert material and improvement in techniques to reduce the bonded materials.

5.3. Effect of Productivity Index (PI) on Capital Cost

The results showed that productivity had positive influence on capital cost. The proportion of labor cost accounted for 9–32% of the PFC production cost in our study, though previous studies revealed that labor requirement be reduced compared with in traditional on-site construction [9,19]. The results were due to lack of technical personnel and lower productivity of continuous production in prefabrication, which brought with the high labor cost. Others, the labor requirement was still increasing because of the immaturity of technology and resources in the early stage of prefabrication. Our study suggested that project managers reduce capital cost by improving productivity.

5.4. Effect of Construction Dissipation Index (CDI) on Capital Cost

Construction dissipation plays an important role in capital cost management. Our study confirmed that construction dissipation results from production and installment processes. Previous studies revealed that attrition ratio of components production was lower at a factory compared with on-site construction. However, this study found that the attrition ratio of PC was high in transport and installation processes. This results from transport machinery, storage methods of PC and installation methods etc. Moreover, our study also found that the Cp accounts for 70–85% of the capital cost but the Ci should not be ignored. On-site installation management has a positive effect on capital cost management. The results attributed to added cost for prefabrication, i.e., high-power tower crane, storage cost of PC and storage cost of PC etc.

5.5. Effect of Design Efficiency Index (DEI) on Capital Cost

The design efficiency has an important effect on reducing capital cost while the Cd account for a small proportion of the capital cost. Different in traditional on-site construction mode, the stakeholders paid more attention on the Cp in prefabrication construction mode. However, the Cp was not only determined by the producers but also determined by the designers. The results attributed to the important role of the designer plays on produce, transport and on-site install processes. Similar to the previous studies [63], our study confirmed that design efficiency reduce the amortization costs and depreciation amortization in five cases.

6. Conclusions

High capital cost was the most significant barrier to prefabrication development [11,12,29]. This study identified the variables affecting the high capital cost, explored the latent factors, developed the FAEM, conducted case application and then reduce the capital cost. MI, CDI, PI, DEI, TDI, MII and DAI were the latent factors affecting the high capital cost of prefabrication [84]. MI was the most important factor, representing 14.765%.

Collaborative management can reduce capital cost. Cost management was not a simple linear combination [61,85,86]. This study found that although each department try its best to do its own work, the outcome still turned out to be dissatisfied [85]. The phenomenon can be explained by the collaboration management and efficiency externality [87,88], similar to "1 + 1 < 2". Cost management can be conducted in a collaborative management mode through all the processes and elements [89]. Hence, the element was implemented to not only pursue its own benefits but also to consider the benefits of other relevant elements [90].

Innovation can increase cost performance. Innovation was an important driver for improving productivity and efficiency [27,68]. Technological innovations can solve the technical problems [11], e.g., joint problems, reinforcement optimization and wall thickness. Material innovation can reduce material cost [91]. For example, new sealant materials should be explored to replace the costly Sunstar sealant. Moreover, production engineering innovation can improve productivity, which was only 20% in many PC factories.

Detailed design was conducive to cost performance. Design determines the various attributes of the prefabrication [92]. As for prefabrication, detailed design significantly influences cost performance. For example, design standardization contributed to PC standardization [73], which can facilitate the economies of scale and improve resource utilization. Moreover, design determines the attributes of PC [93]. The reasonable size, shape and weight of PC were conducive to reducing transportation and crane hoisting cost, as well as improving the efficiency of installation workers and production line [11,29,92].

The location of PC factories should be determined with consideration into economics outcomes and reasonability. The Ct of PC was affected by transport radius (Rt) and transport efficiency (Et). A longer Rt tend to increase the Ct. On the other hand, a higher Et would decrease the Ct. Meanwhile, a shorter Rt can reduce the damage ratio, storage cost of PC on-site and time limit for a project delay risk [11,94]. Technical innovation by PC factories has been attempted, e.g., a "Mobile Precast Concrete Component Factory", in which the equipment for production can be relocated and moved, like the nomadic method of Mongolia on the grassland. All these factors can reduce the capital cost of prefabrication.

Targeted strategies can be designed for prefabrication projects of different characteristics and the pre-action management should be conducted. This research explored the evaluation set X for selection. Specifically, X is a set of variables affecting the capital cost of prefabrication, $X = (x_1, x_2, \ldots, x_{26})$; x_1 represents FC2; and x_{26} represents FPT5. On-going management has a significant effect on cost management. These variables may change the on-going processes, which should be monitored timely. Then, dynamic management can be carried out for the potential variables. Also, after-action management was beneficial for project appraisal and cost management, especially in the next prefabrication project management [51].

In sum, this paper explored the variables affecting the high capital cost of prefabrication and developed the FAEM for cost optimization. A limitation of this research is the small number of cases involved and analyzed in China. Moreover, the weight of indexes was determined by experts" subjective judgments, which mainly relies on the experience and knowledge of experts. However, the results of this study were consistent with the previous studies of a similar nature and can be generalized to a wider community. Hence, this study provides stakeholders and decision makers with valuable references to make strategies and policies for cost management. This study contributes to the literature by exploring the variables set X and index set f and building the comprehensive evaluation model of FAEM. The findings can provide a reference to cost management of prefabrication.

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