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Critical Success Factors for Project Planning and Control in Prefabrication Housing Production: A China Study

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Abstract: The process of prefabrication housing production (PHP) has been inevitably faced with diverse challenges. A number of factors affect the successful implementation of PHP. However, the critical success factors (CSFs) remain unrevealed. This paper aims to examine the CSFs for the planning and control of PHP projects. A total of 23 factors were identified as a result of literature review, in-depth interviews and pilot studies with experts in the construction industry. A questionnaire survey was conducted with designers, manufacturers, and contractors in China. The result showed that the top five CSFs were: (1) designers' experience of PHP, (2) manufacturer's experience of PHP, (3) project manager's ability to solve problems, (4) maturity of techniques used in the detailed design phase, and (5) persistent policies and incentives. The 23 CSFs were further categorized into five groups via exploratory factor analysis, namely: (1) technology and method, (2) information, communication and collaboration, (3) external environment, (4) experience and knowledge, and (5) competence of the project manager. In particular, "technology and method" played the dominant role. This study contributes to the existing body of knowledge via a holistic approach covering the key actors of PHP such as designers, manufacturers as well as contractors to examine CSFs of PHP. These findings provided designers and project managers with a useful set of criteria for the effective project planning and control of PHP and facilitated the successful implementation PHP.

Keywords: prefabrication housing production; planning and control; critical success factors; China

1. Introduction

Prefabrication housing production (PHP) has been widely promoted all over the world to improve quality, reduce waste and energy consumption, and provide a safer work environment [1–3]. Similar terms used in different countries or regions include "off-site production or off-site construction", "industrialized building/housing/construction", "prefabrication, preassembly, modular and off-site fabrication", and "prefabrication construction" [4–6]. PHP is an emerging construction method in which building components can be produced in a controlled environment and assembled quickly on site. According to previous PHP practices in different regions in the world such as Sweden, Singapore, and Malaysia, additional complexity is introduced into PHP because of more requirements for cooperation and coordination [7–9]. In addition, PHP has a higher demand for information delivery across all stakeholders in the supply chain and is more complex in terms of project planning, organization, coordination, and communication [10]. Compared to the construction process of non-prefabricated houses, the organization of PHP is more complicated because of the inclusion of more new stakeholders, such as offshore manufacturers, transporters, and local authorities [11]. Consequently, these kinds of complexity will lead to inefficiencies and uncertainties in PHP and will present new challenges for the planning and control of projects [12]. Therefore, the planning and control of PHP become more difficult due to the increased challenges and complexity.

In addition to traditional project objectives (i.e., time, cost, quality, and safety), productivity and sustainability are project objectives of PHP [13]. This is due to the rapid urbanization process and the growing demand to achieve a resource-conscious and environmentally friendly society [14,15]. Due to available resources and various project features, PHP's performance is not always better than on-site construction methods. For example, previous studies have identified a large number of barriers to PHP practices (e.g., lack of policies and regulations, technical difficulties, high costs, and fragmented industry structure and supply chain) [5,16–18]. The majority of issues that lead to delay, poor quality, and cost overrun in PHP are in the construction stage where the process of installation and erection is carried out [19]. Stricter planning and control measures should be adopted in the design, components production, and assembly process in order to achieve these objectives These measures include fewer design changes, more effective materials logistics management, a higher degree of standardization, and a more reliable components production schedule [20–23]. If not employed appropriately, PHP may suffer from a series of issues such as production delays, substantial cost overruns, and order change [24,25].

A considerable number of studies have been conducted on project critical success factors (CSFs). However, there is no consensus regarding the factors that influence the success of PHP projects [26,27]. Previous studies have shown that project success factors are not common to all types of projects. Many researchers had identified CSFs that are specific to certain kinds of projects such as public–private partnerships (PPP) infrastructure projects, six sigma projects, international construction projects, and green building projects [28–31]. However, few studies have explored CSFs to improve their project planning and control (PP&C) outcomes in PHP. The study conducted by Ismail et al. (2012) on management factors for PHP is an exception. Only management-related factors were highlighted in Ismail's study [32]. Other factors such as supply chain-related factors, technical factors, and industry-related factors were largely overlooked. PHP has undergone rapid growth in China in recent years, thus providing the opportunity for a comprehensive investigation. As such, the overall aim of this study is to fill this research gap in the field of PHP by identifying CSFs. The specific objectives are to (1) identify the CSFs of PHP projects, (2) explore the underlying relationships among factors related to the successful implementation of PHP, and (3) provide a useful reference for key stakeholders of effective PP&C of PHP. The next section provides a literature review.

2. Literature Review

2.1. PHP in China

PHP has been gradually adopted in China since the middle 2000s [14,15,33]. This is due to common factors such as the sustainable development of the national economy, the growth of labor costs, and the increasing demand for sustainability. Over the past half-century, PHP in China went through various stages: an initial development stage (1950–1970s), an exploratory development stage (1980–early 2000s), and an expansion development stage (middle 2000s–now) [15]. With the growing demand for environmental protection and labor shortages in China, PHP has been developed and expanded gradually since the middle 2000s. Especially in the past three years, the government has released a lot of policies and initiatives in order to promote the adoption of PHP. An increasing number of developers such as Vanke Corporation, Beijing Uni-construction Real Estate Development Corporation, and Country Garden have entered the market. More than 100 manufacturing plants specifically designed for PHP have been invested in by companies such as the China Construction Science & Technology Group (Beijing, China), the China Mingsheng Drawing Technology Group (Changsha, China), and Yuhui Construction Corporation (Harbin, China). A variety of building systems such as "prefabricated shear wall structure systems" and "prefabricated reinforced concrete shear wall structural system" have been successfully implemented in China. Under the current situation, all the stakeholders in the industrial chain, such as the government, developers, designers, manufacturers, and general contractors, have started to devote enormous resources to prefabricated buildings. A huge number of PHP projects have started or have been implemented. Research into critical success factors for project planning and control in prefabrication housing production has become crucial. Although many scholars have fully explored CSFs in relation to construction projects, CSFs for PHP have not yet been systematically discussed. Therefore, this research plugs a gap.

2.2. PP&C and Project Success in PHP

Effective planning and control of construction activities are essential to achieving exceptional performance [34,35]. PP&C involve a systematic and iterative process of defining directives, executing and adjusting them according to project feedback [36]. Various project objectives such as delivery on time, keeping the project costs within budget, and meeting the quality requirements must be satisfied to deliver a successful project. Additional objectives such as safety, sustainability, and reliability are equally or even more important in PHP.

Various factors can affect the performance of construction projects. Previous studies have identified many critical success factors (CSFs) for construction projects. Chan et al. (2004) identified five groups of factors influencing the success of construction project implementation, namely project-related factors, project procedures, project management actions, human-related factors, and the external environment. Zwikael and Globerson (2006) explored the impact of 16 planning processes and identified the most sensitive processes for a successful project [37]. Ling et al. (2009) established 24 project practices that were significantly correlated with Singaporean firms' project performances in China, especially those relating to risk management [30]. Li et al. (2011) grouped the factors that affected the successful delivery of green building projects into five components, namely project manager's competence, technical and innovation-oriented factors, human resource–oriented factors, coordination of designers, and contractors' support from designers and senior management [31]. Liu et al. (2014) identified CSFs such as sound feasibility analysis, effective interface management, and effective conflict management that contribute to the success of public–private partnership (PPP) infrastructure projects in different phases. O'Connor et al. (2014) presented 21 CSFs including owner's planning resources, timely design freeze, capability of the fabricator, and heavy lifting equipment for the successful implementation of modularization in projects [38]. Heravi et al. (2015) explored the influence of project stakeholders and identified four critical stakeholder groups including the project owner, developer, designers, and contractors [27].

3. Research Methodology

3.1. Overall Research Framework

The research goal of this paper is to explore the CSFs of PHP. To achieve this purpose, this study follows the research framework proposed by Deng et al. [39] and Arif et al. [40]. Arif et al. identified 17 key variables related to political risk management of international construction companies through literature reviews and pilot studies. In order to research the rank and relationships of affecting factors, the factor analysis and average score methods were introduced in their study [40]. Deng et al. explored the factors that inhibit the promotion of SI system building by conducting an investigation through a questionnaire [39]. Then the mean score method was used to explore critical factors, and factor analysis was applied to explore the potential relationship between initial variables in the questionnaire. The research methodology of this study is based on a literature review, in-depth interviews, a questionnaire survey, ranking, and exploratory factor analysis (Figure 1). Statistical Product and Service Solutions software 19.0 provides professional factor analysis and in this study was also applied to conduct mean score ranking.

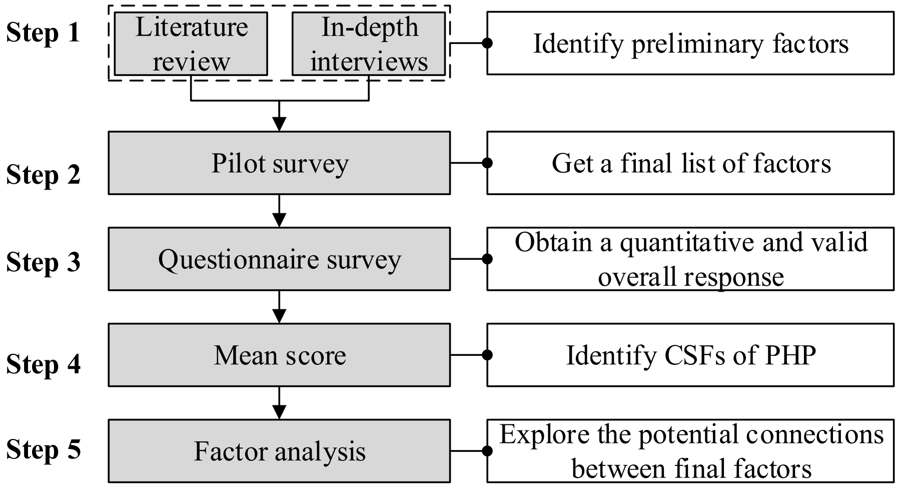

Figure 1. Research methodology flow chart.

3.2. Questionnaire

The preliminary list of variables was formulated based on (1) a literature review, and (2) in-depth interviews with PHP experts. In order to ensure the reliability of the survey, the research group selected five experts with long-term prefabricated construction experience in authoritative enterprises as respondents. The five experts cover all types of related companies. Before conducting a full investigation, a pilot study was conducted with selected experts in the field of construction management to verify the initial list of variables. Five experts who had over 10 years of working experience and participated in more than eight PHP projects were invited to revise the initial list of variables. The profiles of these experts are listed in Table 1. The questionnaire was refined based on the feedback received from the pilot survey. Finally, 23 variables that influence the implantation of PHP were obtained (Table 2).

Table 1. The profiles of the five experts.

Experts	Type	Company	Working Experience	Major	The Number of PHP Projects Participated In
1	Manufacturer	Company A: One of the earliest companies in China to manufacture the prefabricated components, it is very representative as a manufacturer	12	Civil engineering	12
2	Design	Company B: The Company B is one of the largest six design institutes in China and is authoritative in the design of prefabricated buildings.	15	Architecture	20
3	Contractor	Company C: A company with the highest qualification and level in this field of prefabricated construction	12	Civil engineering	10
4	consulting company	Company D: Company D specializes in the consulting of prefabricated housing production	15	Civil engineering	25
5	Contractor	Company C: A company with the highest qualification and level in this field of prefabricated construction	12	Civil engineering	8

Table 2. The preliminary list of 23 factors.

Code	Factors	Sources
F1	Well-developed specifications and regulations	[15,39]
F2	Persistent policies and incentives	[5,41,42]
F3	Sustainability request by the local government	[43,44]
F4	Difficulty to obtain planning permission by the local government	[11]
F5	Designers' experience of PHP	[26,45]
F6	Involvement of the designer during the production and construction stage	[46]
F7	Involvement of contractors and manufacturers during the design stage	[9]
F8	Project manager's proportion of time spent on planning and control	[27,47,48]
F9	Design processes management method	[11,49]
F10	Manufacturer's experience of PHP	[5,23]
F11	Sufficiency of manufacturers and suppliers of prefabricated components	[11,39]
F12	The quality management method of prefabricated components	[15,50]
F13	Rationality of the transportation method of prefabricated components	[11,51]
F14	The maturity of manufacture technology	[52]
F15	Skills and knowledge of labors	[15,17,39,53]
F16	Project manager's ability to solve problems	[54]
F17	Effective communication among participants	[9,55,56]
F18	Project manager's attitude towards planning and control	[27,47,56]
F19	Information sharing among participants	[10,57]
F20	The maturity of techniques used in the detailed design phase	[11,58]
F21	Efficient coordination between off-site and on-site	[59]
F22	Adoption of Information and communication technology (ICT) such as building information modeling (BIM), enterprise resource planning (ERP), and radio frequency identification (RFID)	[60–63]
F23	Rationality of the assembly planning method	[52,64]

The survey was conducted in March–May 2017. A snowball sampling technique was adopted because of the lack of sampling framework. A similar technique was used in studies by other scholars [5,39]. By means of the snowball sampling technique, the questionnaire can be shared through social networks by the initial respondents (e.g., 25 initial respondents from popular design, manufacturing, and construction firms in this research) to approach a wider range of respondents. This questionnaire was distributed to 400 professionals (designers, manufacturers, and contractors). They are the main actors in the supply chain of PHP and have a significant influence on PP&C of PHP [11,13]. A total of 136 valid responses were obtained, including 42 from designers, 43 from manufacturers, and 51 from contractors. Therefore, the response rate of this study is 34%, which was higher than in similar studies (28.2%) conducted by Yuan [65] and Liu et al. [66] (25.8%) in the building and construction industry in China. Additionally, this rate was higher than the average response rate, ranging from 20% to 30% in the construction industry [67,68]. Therefore, this sample was adequate for data analysis. The profile of the sample group indicated that 12.5% of the respondents were senior managers, 34.56% were middle managers, and 52.94% were engineers and technicians. The majority of the respondents (83.8%) have more than three years of experience in PHP. In addition, 36% of the respondents have more than five years of experience. Considering that China's prefabricated houses were built on a large scale after 2015, the survey participants are reliable.

In addition, the average years of working experience of the respondents was 5.4 years, which is higher than in a similar study conducted in Cao et al. [39] (2.4 years); the maximum years of experience in PHP of the respondents was 15. This result was acceptable as most of the PHPs in China were completed in the last 10 years, as stated by Zhang et al. [15]. This research result was consistent with previous studies (2014) as the precast concrete frame was the main form of PHP. This survey covers most of the regions in China that have developed PHP. The geographical distribution of the respondents is shown in Figure 2.

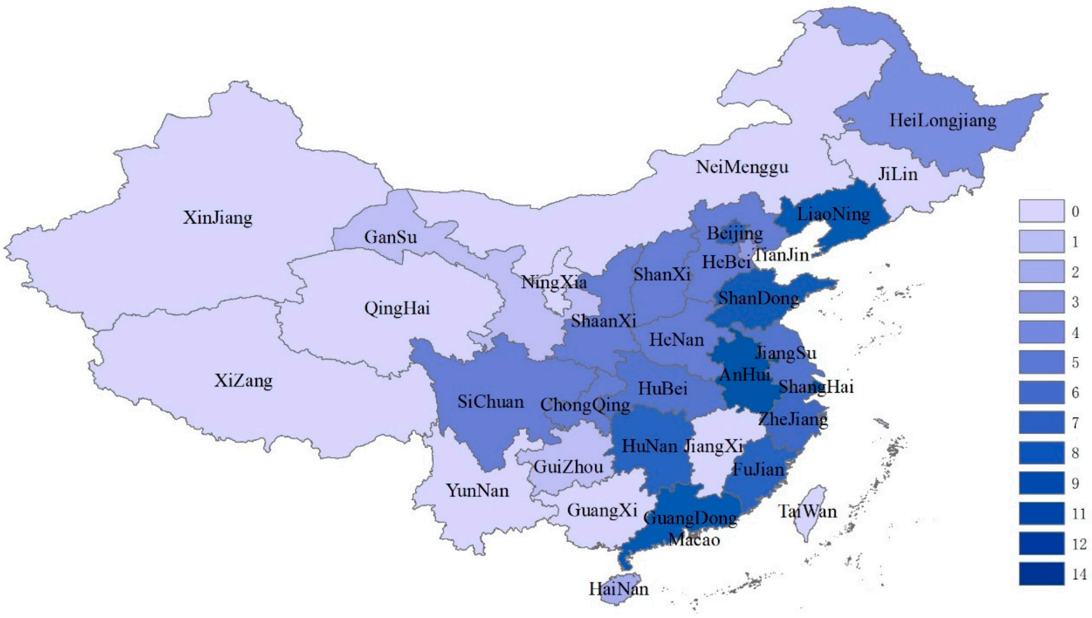

Figure 2. Geographical distribution of the respondents.

4. Data Analysis Method

In order to rank the importance of variables, the mean score (MS) method is introduced into this research. The five-point Likert scale (1 = Least important, 2 = Slightly important, 3 = Important, 4 = Very important, and 5 = Most important) was used to calculate the MS of each factor. To check whether respondents in three key stakeholders (designers, manufacturers, and contractors) gave the same ranking, the MS of the individual variable under the same category was analyzed. MS showed the relative importance of each factor. The MS method is usually considered as a research method to rank the relative importance of factors [40,66]. If the MS of several factors is exactly the same, the factor with the lower standard deviation (SD) is assigned a higher level. Furthermore, factor analysis, which is a statistical method to detect clusters of related variables [39], was used to group variables into a small number of underlying factors. In this study, factor analysis was used to explore the interrelation of 23 variables so that critical factors contributing to the implementation of PHP can be obtained. The frequencies of the responses and their percentages are shown in Table 3.

To test whether each variable was significantly important to the implementation of PHP, a one-sample t-test was conducted. Considering the five-point Likert scale, 3.00 is the mid value, that is, the test value [5]. As shown in Table 4, all 23 variables had significant importance, meaning that the p-values were below 0.05 and the mean scores were above 3.00. Several issues and tests have been widely considered and used in previous studies to determine whether each group of data is suitable for performing factor analysis [39,40]. In this study, the procedure recommended by Deng et al. was followed [40]. The ratio of the sample size to the number of variables is 6, which was higher than the ideal ratio of 5:1. So, for the factor analysis, the sample size is already sufficient. The Cronbach's alpha is 0.875, which is higher than the desired 0.80. This indicates that all data are reliable. The Kaiser–Meyer–Olkin (KMO) index should be greater than or equal to 0.5, while the Bartlett's test of sphericity ($p < 0.05$) should be used to verify whether factor analysis is suitable for data analysis.

Table 3. The frequencies of the responses and their percentages.

F	Least Important	Slightly Important	Important	Very Important	Most Important	Mean Value
F1	2 (1.47%)	7 (5.15%)	33 (24.26%)	66 (48.53%)	28 (20.59%)	3.82
F2	0 (0%)	3 (2.21%)	25 (18.38%)	67 (49.26%)	41 (30.15%)	4.07
F3	2 (1.47%)	7 (5.15%)	34 (25%)	61 (44.85%)	32 (23.53%)	3.84
F4	3 (2.21%)	6 (4.41%)	27 (19.85%)	73 (53.68%)	27 (19.85%)	3.85
F5	0 (0%)	1 (0.74%)	6 (4.41%)	36 (26.47%)	93 (68.38%)	4.63
F6	1 (0.74%)	1 (0.74%)	41 (30.15%)	63 (46.32%)	30 (22.06%)	3.88
F7	1 (0.74%)	2 (1.47%)	39 (28.68%)	58 (42.65%)	36 (26.47%)	3.93
F8	0 (0%)	1 (0.74%)	53 (38.97%)	59 (43.38%)	23 (16.91%)	3.76
F9	3 (2.21%)	8 (5.88%)	31 (22.79%)	65 (47.79%)	29 (21.32%)	3.8
F10	0 (0%)	4 (2.94%)	5 (3.68%)	44 (32.35%)	83 (61.03%)	4.51
F11	1 (0.74%)	6 (4.41%)	26 (19.12%)	77 (56.62%)	26 (19.12%)	3.89
F12	3 (2.21%)	17 (12.5%)	60 (44.12%)	32 (23.53%)	24 (17.65%)	3.42
F13	4 (2.94%)	7 (5.15%)	59 (43.38%)	40 (29.41%)	26 (19.12%)	3.57
F14	1 (0.74%)	9 (6.62%)	57 (41.91%)	55 (40.44%)	14 (10.29%)	3.53
F15	3 (2.21%)	13 (9.56%)	24 (17.65%)	29 (21.32%)	67 (49.26%)	4.06
F16	0 (0%)	2 (1.47%)	18 (13.24%)	77 (56.62%)	39 (28.68%)	4.13
F17	0 (0%)	1 (0.74%)	48 (35.29%)	59 (43.38%)	28 (20.59%)	3.84
F18	0 (0%)	0 (0%)	40 (29.41%)	67 (49.26%)	29 (21.32%)	3.92
F19	0 (0%)	3 (2.21%)	47 (34.56%)	58 (42.65%)	28 (20.59%)	3.82
F20	3 (2.21%)	5 (3.68%)	17 (12.5%)	61 (44.85%)	50 (36.76%)	4.1
F21	0 (0%)	2 (1.47%)	47 (34.56%)	54 (39.71%)	33 (24.26%)	3.87
F22	5 (3.68%)	9 (6.62%)	39 (28.68%)	65 (47.79%)	18 (13.24%)	3.6
F23	2 (1.47%)	7 (5.15%)	33 (24.26%)	66 (48.53%)	28 (20.59%)	3.82

Table 4. Results of MS method and factor analysis.

Code	Mean Value	SD	*p*-Value	Rank	Components				
					1	2	3	4	5
F23	3.897	0.913	<0.001 [a]	9	0.852	-	-	-	-
F14	3.566	0.956	<0.001 [a]	22	0.842	-	-	-	-
F22	3.603	0.929	<0.001 [a]	20	0.738	-	-	-	-
F20	4.103	0.913	<0.001 [a]	4	0.689	-	-	-	-
F12	3.419	0.993	<0.001 [a]	23	0.670	-	-	-	-
F9	3.801	0.917	<0.001 [a]	18	0.646	-	-	-	-
F13	3.581	0.970	<0.001 [a]	21	0.537	-	-	-	-
F6	3.882	0.780	<0.001 [a]	11	-	0.789	-	-	-
F7	3.926	0.822	<0.001 [a]	7	-	0.747	-	-	-
F19	3.816	0.781	<0.001 [a]	16	-	0.740	-	-	-
F21	3.868	0.796	<0.001 [a]	12	-	0.733	-	-	-
F17	3.838	0.752	<0.001 [a]	14	-	0.698	-	-	-
F3	3.838	0.896	<0.001 [a]	15	-	-	0.805	-	-
F11	3.890	0.786	<0.001 [a]	10	-	-	0.760	-	-
F4	3.846	0.868	<0.001 [a]	13	-	-	0.654	-	-
F1	3.816	0.871	<0.001 [a]	17	-	-	0.651	-	-
F2	4.074	0.757	<0.001 [a]	5	-	-	0.641	-	-
F5	4.625	0.608	<0.001 [a]	1	-	-	-	0.847	-
F10	4.515	0.710	<0.001 [a]	2	-	-	-	0.845	-
F15	4.059	1.121	<0.001 [a]	6	-	-	-	0.768	-
F16	4.132	0.686	<0.001 [a]	3	-	-	-	-	0.764
F18	3.919	0.633	<0.001 [a]	8	-	-	-	-	0.737
F8	3.765	0.733	<0.001 [a]	19	-	-	-	-	0.720
Cronbach alpha					0.883	0.803	0.824	0.798	0.708
Initial eigenvalues					6.567	3.861	2.160	1.464	1.405
Variance (%)					28.553	16.786	9.392	6.366	6.111
Cumulative variance (%)					28.553	45.339	54.732	61.097	67.208

[a] The one-sample *t*-test result is significant at the 0.05 level (two-tailed).

5. Research Findings and Discussion

5.1. Ranking of the Factors

This section aims to research those factors that have the greatest impact on the PP&C of PHP on the basis of the MS method. The mean values in Table 4 range from 3.419 for the factor quality of prefabricated components to 4.625 for the factor designers' experience of PHP. This result proved that all the respondents considered these 23 factors to be critical to PHP. As for the ranks of the 23 factors in three categories, as respondents in different stakeholders had different knowledge and roles, their ranks were not completely consistent. The top five factors according to the overall ranking are discussed further.

5.2. Designers' Experience of PHP

The most critical factor to the successful implementation of PHP is designers' experience of PHP (mean value = 4.625). Respondents in the three categories all agreed that this variable was the most significant. Designers' performance, from inception to completion, is critical to a successful project [26]. The design of PHP is very different from the conventional design. On the one hand, the design must be largely finished prior to the production. The fast production and assembly of building components need accurate design. On the other hand, the design changes can reduce the benefits of PHP because of the high rework cost, as indicated in a PHP project in Sweden [45]. Incompetent design may ultimately lead to production quality problems such as joint failure, poor thermal insulation, and water vapor penetration. In addition, PHP has a greater advantage in terms of component standardization and modularity [16]. If designers have adequate experience on the standardization of design, there will be an improvement in both the project constructability and the speed of construction.

The architectural design and the detailed design of prefabricated components in PHP projects are clearly separate in China. This is evidenced by the fact that the manufacturer is only a subcontractor. Designers' experience of PHP would have a significant influence on the subsequent detailed design of prefabricated components. As the detailed design takes inputs from customer requirements and architectural design, it is important for both manufacturing and on-site construction [61]. An experienced designer would consider requests from manufacturing and construction before going ahead. The design result completed by experienced designers would eventually bring value to the construction, e.g., fewer design errors, more efficient manufacturing productivity, and lower cost.

5.3. Manufacturers' Experience of PHP

Manufacturers' experience of PHP was ranked the second most important factor (mean value = 4.515). The ranking of this variable in the three categories was consistent. The importance of this factor to the implementation of PHP has been recognized in various PHP markets such as Singapore, Taiwan, the USA, and Turkey. The manufacturing phase is an extra stage compared with the traditional construction method [18,51]. However, in terms of prefabricated structural components such as precast walls, the advantage of quick installation would be undermined by work delays caused by poor management of manufacturing. It has been recognized in PHP projects in Singapore that late delivery by the precast components' manufacturers is the most common issue for the main contractors [59]. The knowledge and experience of production managers are crucial to consider when making production plans to achieve on-time delivery [69]. For projects located in the downtown, the potential delays caused by traffic congestion and strict size and load restrictions on transportation [70] must be considered when delivering prefabricated components from manufacturers' plants to the construction site.

The quality of the prefabricated components significantly influenced the installation productivity. Physical damage to the components frequently occurred, especially during the storage and transportation process. Without rich experience in practice, physical damage to the components, such as corners and broken ribs, would happen without using appropriate battens during stacking.

Moreover, the probability of damage to finished components increases when conducting loading and unloading tasks [71].

5.4. Project Manager's Ability to Solve Problems

The project manager's ability to solve problems was ranked the third most important factor (mean value = 4.132). This result is consistent with the findings of Jabar et al. (2013a), whose study was based on a survey of the Malaysia PHP market [54]. As the problem-solving skill was the most important competency of a project manager apart from technical knowledge. Only the ranking of this variable in the designers' group was not consistent. "F6: Involvement of the designer during the production and construction stage" was ranked third by the respondents in the designers group. This result indicates that the respondents in the designers group are more concerned with the association between designers and subsequent activities. The project manager is the person in the PHP project who coordinates on-site and off-site activities and is responsible for the project objectives. The time taken for vertical transportation of prefabricated components depends on the weight and size of the prefabricated components and the loading capacity of available hoists and cranes [17]. In this circumstance, the project manager needs to reduce the duration of the subsequent activities to control the overall construction schedule.

5.5. The Maturity of Techniques Used in the Detailed Design Phase

The maturity of techniques used in the detailed design phase is ranked the fourth most important factor (mean value = 4.103). The ranking by manufacturers and contractors is consistent with the overall ranking, as their activities are all affected by the upstream stakeholder. The detailed design is a multi-disciplinary design that includes assembly design and analysis, mold design, and piece and connection design. The detailed design phase is essential in PHP as the role of detailed design is to transform construction drawings into assembly drawings, in which the dimension of each component and the connection method are labeled. In China, the detailed design process is very time-consuming as the detailed design process is based on two-dimensional computer-aided design (CAD) drawings. Taking the external wall as an example, this process is dependent on the designer's knowledge to determine which part of the wall can be prefabricated. Then the detailed assembly drawings of the wall are produced based on the location of the wall, the design specification, and the production constraints. If there are design changes, the detailed design needs to be reprocessed to keep consistent with the overall design of the building.

Sacks et al. (2004) had proposed that the design and detailing tasks of precast concrete should be automated [72]. With the development of three-dimensional (3D) modeling software and building information modeling (BIM) technology, the way building information is represented and managed has the potential to be revolutionized [52]. Although the value of BIM has been recognized by designers in the construction industry, the applications of BIM are limited to visualization, collision detection, and construction simulation [60,73–75]. In terms of the detailed design of a PHP project, numerous limitations related to the information exchange in both geometric shape information and other semantically meaningful information between architects (the Industry Foundation Classes (IFC) format) and fabricators (the Standard ACIS Text (SAT) format) have impeded the BIM technology in the detailed design phase [58]. The data interoperability between the software widely used by designers (e.g., Autodesk Revit, Tekla Structures, ArchiCAD, and Graphisoft) in the construction industry and the software that was popular in manufacturing (e.g., Catia, Solidworks, and Unigraphics (UG)) has not yet been achieved.

5.6. Persistent Policies and Incentives

The persistent incentive policies factor took fifth place (mean value = 4.074). The ranking of this variable in the three categories is consistent as the policies have a common influence on all stakeholders. The adoption of prefabrication involves capital investment and technology innovation when no mature technical systems exist, especially in developing countries such as China and Malaysia. When the PHP is still in its infancy, contractors are more willing to choose a mature method rather than new ones without incentives from local government [39]. In European countries, China, and Australia, the government plays a crucial role in the construction industry. Government policies should be favorable to the prefabrication initiative in order to increase the adoption of prefabrication [41,76]. In the last five years, a growing number of contractors in China have invested in precast concrete plants due to the government's preferential policies. It is apparent that persistent incentive policies have promoted the development of PHP in China.

5.7. Exploratory Factor Analysis

There are three steps in factor analysis: a test for suitability of data, factor extraction, and factor rotation. The value of KMO of this study is 0.806, which is higher than the minimum desirable value of 0.5, and Bartlett's test of sphericity was statistically significant (x^2 = 1733.497, df = 253, $p < 0.001 < 0.05$). This result proved that factor analysis can be used in this study.

This study uses a combination of varimax rotation method and principal component analysis to analyze all 23 factors. After that, five clusters with eigenvalues greater than 1 were extracted, accounting for 67.208% of the variance (Table 4). Each of the 23 CSFs belongs to only one cluster, with a factor loading value greater than 0.5. The number of initial variables in all five clusters is greater than or equal than three. Therefore, the factors in each cluster can accurately reflect the features [39].

All the affecting factors are divided into five clusters through principal component analysis. The five clusters can be labeled as (1) technology and method; (2) information, communication, and collaboration; (3) the external environment; (4) experience and knowledge; and (5) the competence of the project manager.

5.7.1. Cluster 1: Technology and Method

The cluster "technology and method" consists of seven CSFs, namely (1) the rationality of the assembly planning method; (2) the maturity of the manufacturing technology; (3) the adoption of information communication technology (ICT) such as BIM, enterprise resource planning (ERP), and radio frequency identification (RFID); (4) the maturity of the techniques used in the detailed design phase; (5) the quality management method of prefabricated components; (6) the design processes management method; and (7) the rationality of the transportation method of prefabricated components. This cluster reveals 28.553% of the total variables.

This cluster involves factors related to technologies and methods used in different stages of a PHP project such as design, manufacture, transportation, and assembly. As the design stage accounts for more than 70% of the cost and has a significant influence on a project, it is the earliest stage at which new technologies have been applied. Accurate design is required in the PHP to avoid design changes in the production and construction stage. There is a need for technological enhancement in the design, manufacturing, and construction process, especially for improvement in the design and construction technology. As for the design technology, some Chinese design firms are still based on two-dimensional (2D) application tools such as AutoCAD for drafting, while some design firms are trying to transition to a BIM platform such as Autodesk Revit. In addition, during the production process, BIM can be combined with an automatic production line by providing component dimensional information for the detailed component diagram. The automatic production line uses a computer-aided design to computer-aided manufacturing (CAD-CAM) controlled concrete distributor to spread the right amount of concrete according to CAD and robots to place the mold and reinforcement [77].

It is recognized that design automation dramatically improves the productivity of the PHP project as a variety of design rules and constraints were imposed by the manufacturer and the client. The configuration system proposed by Jensen et al. [78] can support and facilitate the design automation by adding rules in SolidWorks (a manufacturing CAD tool) and sharing information through Extensible Markup Language (XML) with Autodesk Revit. Design processes management methods are also important to PHP. One well-known design processes management method is the design structure matrix (DSM) method, which represents the complex design processes in a matrix form. DSM can expose the driver of rework clearly and early to avoid potential risks during project planning [79]. The sequence deviation quotient (SDQ) is another design processes management method proposed by Haller et al. to detect and control superfluous iteration as well as control the risk of time overruns and quality issues within the design phase of PHP [45].

The assembly planning has influences on the manufacturing process as the manufacturer must deliver the prefabricated components to the construction site prior to assembly. Push and pull are two familiar planning methods. In contrast with the traditional planning method, which is "push"-based, lean construction advocates for a planning method that is "pull"-based [64]. Most contractors in China adopted the push method. Consequently, all the prefabricated components have been produced beforehand and delivered to the construction site. As the prefabricated components such as precast concrete components are usually bulky, they will block the construction site [59]. Meanwhile, it is difficult to search for the appropriate component from the storage stacks, which increases the assembly cost. When using the pull method, the components are delivered to the construction site only if the contractor needs it.

The manufacturing technology involves mechanization and automation. The level of mechanization is higher than the level of automation in China. Investment in various machines (e.g., casting machines that pour the concrete onto tables with high accuracy, tilting tables designed for the manufacture of large reinforced concrete elements, and floating machines to smooth the surface finish of precast products) in the precast concrete plant improves productivity.

Although the level of mechanization is relatively high in China, sometimes the quality of prefabricated components cannot satisfy the requirement of customers. Low precision of junction and broken nibs are the two main quality issues. Such quality issues often caused repair or rework. As these issues were detected at the construction site, the resulting costs are higher than be detected in the plant. Six Sigma theory and total quality management have been used in the manufacturing industry to improve the quality of products [80]. The precast concrete firms should use these quality management methods to avoid these quality issues.

The transportation cost of precast components is jointly determined by the number of truckloads used in the delivery process and the unit cost of delivery. The weight and size of the precast concrete components to be transported mainly affect the number of truckloads. The unit cost of delivery is directly affected by the distance between the manufacturer's plant and the construction site [16].

5.7.2. Cluster 2: Information, Communication, and Collaboration

The "information, communication, and collaboration" cluster consists of five CSFs: (1) involvement of the designer during the production and construction stage, (2) involvement of contractors and manufacturers during the design stage, (3) information sharing among participants, (4) efficient coordination between off-site and on-site, and (5) effective communication among participants. This cluster reveals 16.786% of the total variables.

The information required in the management of PHP includes materials, prefabricated components, quality inspection, inventory, and transportation. Traditionally, the information was recorded in notebooks. Data will be entered into the computer for control processing until engineers return to the office. There are spatial and time gaps between the plant (on-site) and the office, which increases the difficulty of communication [81].

The precast concrete systems have two major advantages, namely low cost and speedy erection. Only when good coordination is achieved among all the key stakeholders involved in a project can problems such as delays in production, erection schedules, and constructability be avoided [16]. A huge amount of rework may also be needed in the design stage due to the inefficiency of communication between the designer and manufacturer. Moreover, the contractor's good communication with the designer and the manufacturer is also essential to the success of the project in the erection stage [16].

Prefabrication also required advanced coordination between professionals [51]. Close coordination between prefabrication and construction processes is needed as these two groups of activities run in parallel [61]. Stakeholders in the supply chain should communicate with each other as early as possible in order to improve business efficiency [4].

5.7.3. Cluster 3: External Environment

The cluster "external environment" consists of five CSFs: (1) sustainability request by the local government, (2) sufficiency of manufacturers and suppliers of prefabricated components, (3) difficulty of obtaining planning permission from the local government, (4) well-developed specifications and regulations, and (5) persistent policies and incentives. This cluster reveals 9.392% of the total variables. Various studies suggest that the environment includes many aspects such as economy, politics, society, and industry [26,30] as external factors affecting the project's success. The factors belonging to this "external environment" can be classified into political environment and industrial relation environment.

Well-developed specifications and regulations are also key to the successful implementation of PHP [5]. The specifications and regulations provide the basis for the design of prefabricated buildings, prefabricated components production, quality checking, and evaluation. In the last three years, these specifications and regulations have steadily improved in China. One of the important reasons to promote PHP is the requirement for environmental protection and energy savings [14,82,83], as sustainability is a long-term goal of rapid urbanization. Although some regions in China have created incentives such as tax exemptions and rewards, the process of obtaining planning permission is slow. The design and construction planning must be approved by several agencies.

Designers, manufacturers, and contractors involved in the PHP are the three main stakeholders in the supply chain [11,13]. For the contractor, the manufacturer is the supplier that provides prefabricated components. Therefore, the supplier selection process is important for the planning and control of appropriate components [84]. The manufacturer also needs to order materials such as cement, reinforcement, molds, insulating panels, and concrete admixtures from other upstream suppliers. The precast fabricators must preorder materials before confirming an order to reduce the production time span and decrease the risk of late delivery [22]. If the qualified precast manufacturers are few, a lack of serious competition may lead to higher prices. In the context of China's new urbanization, government incentives of have been the driving force for the advantages of PHP [85]. Government policies have affected market demand and supply as well as the technological update.

5.7.4. Cluster 4: Experience and Knowledge

The "experience and knowledge" cluster consists of three CSFs: (1) designers' experience of PHP, (2) manufacturers' experience of PHP, and (3) skills and knowledge of laborers. This cluster reveals 6.366% of the total variables.

The manufacturers' performance is crucial to the successful promotion of PHP. One of the main factors that hinder performance improvement is a lack of expertise and experience, which may lead to poor design and practices [16]. The above factor may eliminate the advantages of PHP such as predictable schedules. For example, a lack of expertise in components design may cause severe conflicts between manufacturers and designers; a lack of manufacturing experience can cause delays in the flow of deliveries to the construction site; a lack of competence on the part of the contractor can lead to delays in the installation schedule [86]. Furthermore, the on-site assembly and joining of prefabricated components require skilled workers, especially those with machine-oriented skills, both on-site and in the factory [17]. The transition from on-site construction to prefabrication construction requires workers to master new knowledge related to machine operation and maintenance.

5.7.5. Cluster 5: Competence of the Project Manager

The cluster "competence of the project manager" consists of three CSFs, namely (1) the project manager's ability to solve problems, (2) the project manager's attitude towards planning and control, and (3) the project manager's proportion of time spent on planning and control. This cluster accounts for 6.111% of the total variance among all the critical factors (Table 4).

A critical factor affecting communication and planning is the competence of the project manager [26,87]. The conception of competence includes not only knowledge and skills, but also attitudes, behaviors, and work habits [87]. In a PHP project, the project manager needs to coordinate and communicate with relevant stakeholders to achieve the objectives. The project manager should have problem-solving competence, which means being able to identify, analyze, and solve problems [29]. The project manager should invest adequate time to ensure that activities are executed according to the plan or make the plan reliable.

6. Conclusions

The promotion of PHP is complex as it involves a variety of stakeholders as well as activities executed in different locations. These kinds of complexity present significant challenges for PP&C of PHP projects. This study provides a comprehensive list of factors that affect the successful implementation of PHP, based on in-depth interviews, a literature review, and the questionnaire method. This study identified 23 CSFs using the mean score method. The relationships between these critical factors were examined and analyzed by means of factor analysis. Although empirical evidence for this study is from the Chinese PHP market, the methodology derived from this study may provide a reference for similar studies in other PHP markets, according to the characteristics and situations faced in these different environments. Hence, this study contributes to the existing body of knowledge via a holistic approach covering the key actors of PHP such as designers, manufacturers, and contractors and the factors that inhibit the promotion of PHP in the broader global community. The findings of this study can provide stakeholders involved in PHP with a useful set of criteria. Also, the findings would enable PHP practitioners to possess a deeper understanding of the factors that are critical to successful implementation of PHP.

This study identified 23 factors and ranked them in terms of relative importance. All 23 factors were critical as they all have mean scores above 3. The top five CSFs are designers' experience of PHP, manufacturers' experience of PHP, project manager's ability to solve problems, the maturity of the techniques used in the detailed design phase, and consistent policies and incentives. Although these five CSFs were identified based on the Chinese PHP market, significant influences on the implementation of PHP have also been recognized in other countries such as the USA, Australia, Sweden, Turkey, and Malaysia. Factor analysis was used to determine the main factors that affect the PP&C of PHP. The results revealed five clusters that account for 67.208% of the overall factors. The five clusters are (1) technology and method; (2) information, communication, and collaboration; (3) the external environment; (4) experience and knowledge; and (5) the competence of the project manager.

The primary limitation of this study is that not every form of PHP practices was covered. The survey sample mainly covered precast concrete frames as these are the main form of PHP practices in China in recent years. The form of PHP practices may be different according to the characteristics of different regions. Thus, future investigations of various PHP practices in different regions or different stages of development of PHP should be considered in future research.

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