The following publication Wuni, I.Y. and Shen, G.Q. (2020), "Critical success factors for management of the early stages of prefabricated prefinished volumetric construction project life cycle", Engineering, Construction and Architectural Management, Vol. 27 No. 9, pp. 2315-2333 is available at https://dx.doi.org/10.1108/ECAM-10-2019-0534

Critical Success Factors for Management of the Early Stages of Prefabricated Prefinished Volumetric Construction Project Life Cycle

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Abstract:

Purpose – For many types of buildings, prefabricated prefinished volumetric construction (PPVC) is increasingly becoming a preferred alternative construction approach. However, empirical evidence of project performance has consistently demonstrated that the ultimate success of PPVC projects is directly linked to the key decisions made at the outset of the PPVC project life cycle. Meanwhile, there is limited knowledge of how to successfully manage these early stages. This research identified and evaluated the critical success factors (CSFs) required for management of the conception, planning, and design stages of the PPVC project life cycle.

Design/methodology/approach – A multistage methodological framework was adopted to identify and evaluate the CSFs for management of the early stages of the PPVC project life cycle. Based on a comprehensive literature review and pilot survey, a list of the 9 CSFs relevant to the early stages of the PPVC project life cycle was established. Drawing on an online-based international questionnaire survey with global PPVC experts, the CSFs were measured. The dataset was statistically tested for reliability and analyzed using several techniques such as mean score analysis, relativity weightings, and significance analysis.

Findings – The research identified that the most influential CSFs for management of the early stages of the PPVC project life cycle include robust design specifications, accurate drawings and early design freeze; good working collaboration, effective communication and information sharing among project participants; effective stakeholder management; extensive project planning and scheduling; and early engagement of key players such as designers, engineers, fabricators, and contractors. The research further found correlations among the CSFS and proposed a conceptual framework for the management of the early stages of the PPVC project life cycle.

Practical implications – The research identified the key factors that PPVC managers, contractors, and developers should prioritize at the early stages to improve the overall success of PPVC projects. This study may be used as decision support in deciding to implement PPVC in a project and could facilitate informed PPVC investment decision-making.

Originality/value – This research constitutes the first exclusive attempt at identifying the CSFs for successful management of the early stages of the PPVC project life cycle. It provides a fresh and more in-depth understanding of how best to manage the early stages of the PPVC project life cycle. It contributes to the practice and praxis of the PPVC project implementation discourse.

Keywords: early stages; critical success factors; management; PPVC; project life cycle

Please Cite As: Wuni, I.Y. and Shen, G.Q. (2020), “Critical success factors for management of the early stages of prefabricated prefinished volumetric construction project life cycle”, Engineering, Construction and Architectural Management, Vol. 27 No. 9, pp. 2315–2333.

Introduction

The construction industry is a competitive one which imposes the need to adopt innovative technologies and business models to remain competitive and achieve competitive cost advantage. Recurring challenges such as low productivity (McKinsey Global Institute, 2017), dissatisfaction of clients (Egan, 1998), cost escalation, time overrun, high waste footprint (Jaillon et al., 2009), construction defects, poor safety of construction workers (Blismas et al., 2006), and higher emissions of greenhouse gases (Mao et al., 2013) have provoked disruptions in the construction industry. One of such disruptions is the transition towards off-site production, OSP (Wuni and Shen, 2019d). OSP is a construction business model where major components of a building project are manufactured in an off-site factory, transported to the construction site and systematically assembled and installed (Blismas et al., 2006).

Prefabricated prefinished volumetric construction (PPVC) is the most complete form of OSP where value-added fully-finished volumetric building components are manufactured on production lines using advanced precision technology in an off-site factory, trucked to the construction site in sections and systematically craned to form a complete building project (Wuni et al., 2019; Wuni and Shen, 2019a, 2019b). According to Hwang et al. (2018), the business model of PPVC allows for 80-95% of a whole building to be fully engineered in a manufacturing plant. The rapid deployment and effective implementation of PPVC projects, with associated technologies and supply chain arrangements, is leveraging significant gains such as increased productivity, higher construction speed, reduced construction waste, improved safety of construction workers, cost predictability, and improved quality control of construction projects (Blismas et al., 2006; Wuni and Shen, 2019d).

However, not all initiated PPVC projects have achieved the expected level of success (Choi et al., 2016; Wuni and Shen, 2019b). Some key factors and conditions need to converge to achieve success in PPVC projects. Several studies have explored the critical factors required to achieve success in PPVC projects (Choi et al., 2016; O'Connor et al., 2014; Wuni and Shen, 2019b). However, scientific studies of construction project performance have consistently established that the ultimate failure or success of any project is directly linked to the decisions at and management of the early stages of the project life cycle (Wuni and Shen, 2019a). However, knowledge of how to manage the early stages of the PPVC project life cycle is limited and inadequate. There is very little research into the critical success factors (CSFs) for managing the early stages of the PPVC project life cycle. Li et al. (2018) evaluated critical success factors for project planning and control in prefabrication housing production (PHP) in China. However, the study focused on China and PHP and thus has limited application to PPVC projects. Also, Li et al.'s (2018) research adopted a macro perspective of the CSFs and thus offered very little information on the specific CSFs shared among different PPVC project types.

This research aims to identify and evaluate the CSFs for management of the early stages of PPVC projects. The current research makes a unique contribution to the knowledge of the CSFs for PPVC projects and will facilitate a deeper understanding and appreciation of how best to successfully manage the early stages of the PPVC project life cycle. The rest of the paper is structured as follows: The next section offers a concise research background of PPVC and the associated CSFs for PPVC projects, followed by a description of the research approach adopted. The research progresses with a discussion of key results and finally concludes the key findings of the data analysis.

Research Background

Prefabricated prefinished volumetric construction

PPVC is an innovative and disruptive construction method which transforms the linear site-based construction of buildings into an integrated production and assembly of value-added factory-made prefabricated prefinished volumetric modules (Wuni and Shen, 2019b). The Building and Construction Authority (2019) defined PPVC as “a construction method whereby free-standing volumetric modules (complete with finishes for walls, floors, and ceilings) are constructed and assembled in an accredited fabrication facility, following any accredited fabrication method, and then installed in a building under building works." The three major types of PPVC include reinforced concrete modules, steel modules, and hybrid modules. PPVC shares many similarities with other OSP models such as modular construction, modular integrated construction (MiC), modular prefinished volumetric construction, and industrialized building systems (Wuni and Shen, 2019d).

PPVC adopts a manufacturing business model and the philosophy of Design for Manufacture and Assembly (DfMA). DfMA is an engineering methodology which simplifies the design of the building components to ease manufacturing and assembly of the modules (Building and Construction Authority, 2017; Gao et al., 2018). DfMA combines two distinct design principles comprising the Design for Manufacture (DfM) and Design for Assembly (DfA). PPVC incorporates and diffuses the DfMA principles into the early design phases of the project life cycle. The adoption of DfMA in PPVC projects facilitate selection of cost-effective manufacturing-compliant raw materials, minimizes the complexity of the manufacturing operations during the design phase, and eventually reduces manufacturing time, cost of products and assembly time. The supply chain of PPVC involves design, manufacturing, transportation, storage, and components installations (Wuni et al., 2019). Figure 1 shows the basic life cycle of a PPVC project.

[**Figure 1**. The basic life cycle of a PPVC project]

Two critical observations in Figure 1 are that the design stage constitutes an early stage of the PPVC project life cycle, and the remaining stages are highly connected. The design stage of a PPVC project is critical because a crucial decision at this stages influences the activities and decisions in the subsequent stages of a PPVC project (Wuni and Shen, 2019b, 2019a). Indeed, not every design of a project is suitable for modularization, prefabrication, and PPVC (Murtaza et al., 1993). PPVC is most suitable for projects with repetitive design and layouts (Hwang et al., 2018; Wuni and Shen, 2019a). Thus, the design of a project is very decisive in whether PPVC is ideal for a project. In this research, the early stages of a PPVC project life cycle include a conception of the project, planning, and design (architectural and engineering) (Wuni and Shen, 2019c). The completion of these stages is required before the manufacture of the prefabricated volumetric components. Thus, it is imperative to manage this early stage effectively because it is linked to the total success of the PPVC project.

Critical success factors for PPVC Projects

Key success factors (CSFs), key result areas, and success factors are interchangeable terminologies and refer to critical success factors (CSFs) in this research which constitute the few management areas that must be given critical attention and resources commitment (Rockart, 1982) to guarantee the success of PPVC projects. In practice, CSFs are usually few and ranges from 5 to 8 (Freund, 1988). Following the increasing popularity and rapid deployment of PPVC, it is imperative to identify the CSFs for PPVC. Because of the fewer academic research studies on PPVC (Hwang et al., 2018), the associated CSFs can hardly be found in the literature. However, there is some significant amount of studies on the CSFs for other OSP models which can be analyzed to ascertain their relevance to PPVC projects.

[**Table I**. Potential CSFs for PPVC projects (Wuni and Shen, 2019b)]

O'Connor et al. (2014) reported that the most influential CSFs for successful modularization of industrial projects include attention to module envelope limitations, consensus among project participants on project drivers, adequate resources of client, early design free, and early consideration of modularization. Choi et al. (2016) concluded that the most critical CSFs for industrial modular construction projects include timely design freeze, long-lead equipment specification, early engagement of fabricator/contractor, and effective management of execution risk. Li et al. (2018) found that the top 5 CSFs for planning and control of PHP include the experience of designers, the experience of manufactures, capabilities of the management team, use of advanced techniques in the detailed design phase, and favorable design codes and policies. It can be observed that the CSFs are sensitive to project types and territories. Wuni and Shen (2019b) reviewed studies on the CSFs for implementing MiC projects during the period 1993–2019 and established a generic framework of 35 CSFs. The researchers synthesized the CSFs from different OSP techniques and thus offered a useful framework to identify the CSFs with relevance to the early stages of the PPVC project life cycle. The preliminary list of CSFs for PPVC projects which were derived from Wuni and Shen's (2019b) framework is shown in Table I. These CSFs formed the basis for identifying the CSFs for successful management of the early stages of PPVC projects.

Research method and approach

This research employed a quantitative research design where the study identified and evaluated the CSFs required for successful management of the early stages of the PPVC life cycle. The research adopted a multistage methodological framework comprising an identification of relevant CSFs, design of the CSFs measurement instrument, data collection, and statistical analysis of the collected data.

Identifying the CSFs for management of the early stages of the PPVC project life cycle

The research initiated with identifying the CSFs for management of the early stages of the PPVC life cycle in two phases: (1) a literature review and (2) pilot survey. Drawing on the works of Wuni and Shen (2019b), the research developed a preliminary list of the CSFs which were considered relevant to PPVC projects (Table I). Next, a pilot survey was conducted with 3 PPVC experts (two from academia and one from industry) to evaluate the relevance and appropriateness of the CSFs to the conception, planning, and design (architectural and engineering) stages of the PPVC project life cycle. The pilot survey made significant improvements to the tentative list where some CSFs were merged, an additional CSF was added, and some CSFs were reworded, redefined, or omitted. The final list of the CSFs relevant to the early stages of the PPVC project life cycle is shown in Table II and formed the basis of designing the measurement instrument.

[**Table II**. Final list of CSFs for management of the early stages of the PPVC project life cycle]

International expert survey and measurement instrument

This research was based on an international survey where PPVC experts were identified and contacted to evaluate the significance and criticality of the identified CSFs for management of the early stages of the PPVC project life cycle. The international survey approach was adopted because of the following reasons: (1) there was the need to establish a generic framework of the CSFs for management of the early stages of PPVC project life cycle which are shared between countries and different project PPVC project types; (2) there was also the need to draw on rich experiences of experts from many countries, especially where the PPVC technology is developed; and (3) the international survey approach is widely used to generate substantial data within a short time span (Osei-Kyei, Chan, Javed, et al., 2017; Sachs et al., 2007). A purposive sampling technique was adopted to identify the relevant experts from industry and academia. This non-probabilistic technique was adopted because there is no central database of all PPVC experts in the world. Previous international surveys used a similar approach to identify relevant experts and collect reliable data (Osei-Kyei, Chan, Javed, et al., 2017; Sachs et al., 2007).

The PPVC experts were compiled after ten months of PPVC literature review as part of an on-going Ph.D. research project. The target experts were selected based on two criteria: (1) the expert should have rich theoretical and research experience in PPVC projects, and (2) the experts should have hands-on experience in PPVC projects. Four hundred experts were used as the sampling frame. The research designed and administered an online-based structured questionnaire using “Survey Monkey" to collect quantitative data. The questionnaire had two sections: (1) background information and (2) significance/criticality evaluation of the CSFs. Section 1 solicited information regarding the sector of work, number of years of hands-on experience, country of work, and PPVC project type of engagement. Section 2 requested the experts to assess the level of criticality of the CSFs on a 5-point rating scale of 1 = not critical, 2 = fairly significant, 3 = critical, 4 = very critical, and 5 = extremely critical. Personalized emails were written to each of the 400 experts using a combination of Microsoft Word, Excel, and Outlook. A QR-code and web link to the survey was attached in the email. The experts were given four weeks to complete the survey, and after several rounds of reminders, a total of 56 valid responses were collected. Although small, the sample size was considered adequate for reliable analysis because previous international survey analyzed even smaller samples such as 46 (Osei-Kyei, Chan and Ameyaw, 2017), 42 (Osei-Kyei, Chan, Javed, et al., 2017), and 29 (Sachs et al., 2007).

Data analysis protocol

The responses of the experts were coded and analyzed using the Statistical Package for the Social Sciences (SPSS v.25). SPSS was used to conduct several statistical tests, including reliability analysis, data normality tests, mean score analysis, relativity weightings, and significance analysis. The Cronbach’s Alpha (α) test was used to determine the statistical reliability and validity of the survey responses. The α values ranges between 0 and 1, where 0.7 represents the minimum acceptable reliability threshold (Tavakol and Dennick, 2011). Based on the recommendations of Chou et al. (1998), the Shapiro – Wilk test was used to determine whether the dataset is normality distributed. This is crucial because it determines whether parametric or nonparametric statistical techniques should be used to analyze the dataset further. The mean indexes (μ_i) for each CSF was computed using equation (1).

$$\mu_i = \frac{\sum(S \times F)}{N}, \qquad (1 \leq \mu_i \leq 5) \qquad (1)$$

Where, S denotes a score given to each CSF by an expert, ranging from 1 to 5 (1= not critical and 5=extremely critical); F denotes the frequency of each rating (1-5) for each CSF, and N represents the total number of responses for a given CSF. The mean indices of the CSFs were interpreted on an interval scale where a CSF with a mean index of $\mu_i \leq 1.4$, $1.5 \leq \mu_i \leq 2.4$, $2.5 \leq \mu_i \leq 3.4$, $3.5 \leq \mu_i \leq 4.4$, and $\mu_i \geq 4.5$ was considered "not critical", "fairly critical", "critical", "very critical", and "extremely critical", respectively (Osei-Kyei, Chan, Javed, et al., 2017).

For normalization of the mean indices, the relativity index (RI) of each CSF was computed. The RI imposes the need to prioritize CSFs with higher relative weights (Mbachu and Nkado, 2006). The RI compared the mean indices of all the CSFs and computed as a unit of the sum of the mean indices (Mbachu and Nkado, 2006), as shown in equation (2).

$$RI_i = \frac{\mu_i}{\sum_{i=1}^{N}(\mu_i)} \quad (2)$$

Where: N denotes the number of CSFs and μ_i denotes the mean index of given CSF *i*. Effectively, the RI of each CSF represents its relative weightings and normalized mean index. Drawing on the work of Zhang (2005), the research further computed the significance index (S_i) of each CSF. The linear fuzzy linguistic alternatives of the 5-point grading scale (1-5) used in measuring the CSFs in the questionnaire were converted to a linear percentage scale of 20 – 100 with 20 corresponding to the lowest and 100 the highest significance. Effectively, "1", "2", "3", "4", and "5" have the significance indices of 20, 40, 60, 80, and 100, respectively. The significance index of a CSF is computed using equation (3) as follows:

$$\text{Significance index } (S_i) = \frac{1*R_{i1} + 2*R_{i2} + 3*R_{i3} + 4*R_{i4} + 5*R_{i5}}{R_{i1} + R_{i2} + R_{i3} + R_{i4} + R_{i5}} = \frac{20R_{i1} + 40R_{i2} + 60R_{i3} + 80R_{i4} + 100R_{i5}}{R_{i1} + R_{i2} + R_{i3} + R_{i4} + R_{i5}} \quad (3)$$

Where: S_i = significance index for the i^{th} CSF; R_{i1} = number of responses for the grading alternative "1" for the i^{th} CSF; and R_{i5} = number of responses for the grading alternative "5" for the i^{th} CSF. These scores formed the basis for ranking of the CSFs for management of the early stages of the PPVC project life cycle.

Results and discussions

Background information of the international experts

The first section of the questionnaire solicited background information of the experts, and the relevant components are shown in Table 3. Preponderances of the experts (44, 78.6%) were actively working in academia. This unequal sectorial distribution of the experts is characteristic of previous international survey studies (Osei-Kyei, Chan and Ameyaw, 2017; Osei-Kyei, Chan, Javed, et al., 2017). Notably, academic experts have stronger ties with industry and actively provide several services to industry practitioners. Some academic experts have worked in the industry for some time before joining academia, and thus the distribution is fair enough to capture the views of both the academics and industry practitioners.

[**Table III**. Background information of the PPVC experts]

A significant proportion (27, 48.2%) of the experts had below five years of hands-on experience in PPVC projects. This is entirely justifiable becomes PPVC is still fledgling in some countries, with fewer projects been implemented (Wuni and Shen, 2019b). However, these experts had researched and published research articles on PPVC and related OSP models and thus acquired rich theoretical and research knowledge of PPVC implementation. Majority of the experts had over five years of hands-on and practical work experience in PPVC and related OSP models. Indeed, 16.1% of the experts had over 21 years of experience and worked on several PPVC project types. This corroborates the quality of experts used in the study, and hence reliable results are expected from the study. A geospatial analysis showed that the experts have worked on PPVC projects in 18 countries and all continents. These countries (Table 3) comprises developing and developing economies. Therefore, rich and disparate experiences have been integrated into the assessment of the CSFs in the current study. The experts had also worked on different PPVC project types (Figure 2).

[**Figure 2**. PPVC project types associated with the experiences of the experts]

The experts had worked on different PPVC project types (Figure 2) across the 18 countries and six continents. Most of the experts had worked on housing projects (71.4%), commercial buildings (30.4%), schools (26.9%), industrial projects (23.2%), and health projects (17.9%) where PPVC was implemented. This distribution is not a coincidence because these project types have repetitive designs and lend themselves to PPVC (Hwang et al., 2018; Wuni and Shen, 2019a). This further shows that multiple project experiences and lessons were captured in the evaluation of the CSFs, and hence, the results may apply to all these categories of PPVC project types.

Reliability and validity of survey results

Reliability analysis of the dataset for the 9 CSFs for management of the early stages of the PPVC project life cycle generated a Cronbach's Alpha of 0.764, which is above the minimum threshold of 0.7 (Tavakol and Dennick, 2011). This highlights the excellent internal consistency in the responses of the experts and the overall validity of the research instrument used.

Agreement and consistency of survey responses

Before assessing the agreement of the different experts engaged in the study, it was necessary to ascertain whether parametric or nonparametric statistical technique should be used for evaluation. The Shapiro – Wilk test of data normality generated P-values of less than 0.05 at 95% confidence level for all 9 CSFs (Table IV), indicating that the dataset is not normally distributed.

[**Table IV.** Shapiro – Wilk and Kruskal – Wallis tests results of the CSFs]

This outcome imposed the use of a nonparametric technique to ascertain whether there are significant differences in the ratings given by experts from academia and industry. The Kruskal – Wallis test; a rank-based nonparametric technique was used to test the null hypothesis that "there is no agreement or consensus among experts on the rankings of the CSFs for the PPVC projects." The Kruskal – Wallis test generated P-values greater than 0.05 for all CSFs (Table IV), indicating that the null hypothesis can be rejected and hence there are no significant variations in the ranking of CSFs by the experts from academia and industry. This indicates that the responses can be treated holistically.

Mean, relativity and significance indices of the CSFs for PPVC projects

Mean score analysis is widely used to assess the aggregate average rating of a CSF based on Likert scale data (Zafar et al., 2019). It measures the total average evaluation of a CSF by all the experts. Table V shows the mean, relativity, and significance indices of all the CSFs for management of the early stages of the PPVC project life cycle. The three indices, as shown in Table V, were computed using equation (1) to (3), respectively. The significance indices formed the basis for ranking the CSFs for management of the early stages of the PPVC project life cycle.

[**Table V.** Mean, relativity and significance indices of the CSFs for PPVC projects]

The mean score analysis of the CSFs (Table V) for management of the early stages of the PPVC project life cycle generated indices greater than 3.0 on the 5-point grading scale adopted. Based on the definition of the grading points used in the current study, all the CSFs are considered at least critical. The relativity indices are consistent with the mean indices. Based on the significance indices, the top 5 most influential CSFs for management of the early stages of the PPVC project life cycle include CSF2 – robust design specifications, accurate drawings and early design freeze (3.96, 0.120), CSF1 – good working collaboration, effective communication and information sharing among project participants (3.86, 0.117), CSF3 – effective stakeholder management (3.77, 0.114), CSF5 – extensive project planning and scheduling (3.71, 0.112), and CSF9 – early engagement of designer, fabricator and contractor (3.70, 0.112). They all scored mean indices of at least 3.70 and were considered very critical in the management of the early stages of the PPVC project life cycle.

Correlation matrix of the CSFs for management of the early stages of PPVC projects

A correlation coefficient measures the linear association between two variables. It computes the extent to which two CSFs change together in the management of early stages of the PPVC project life cycle. The coefficient describes both the strength and direction of the relationship or association. The two conventional techniques for linear correlation analysis include the Pearson product-moment correlation and the Spearman rank-order correlation. The latter is used in the current study because it is suitable for ordinal data as collected in the current study and assumes a monotonic relationship where the CSFs may change together but not necessarily at a constant rate. Table VI presents the correlation matrix of the 9 CSFs for management of the early stages of the PPVC project life cycle. The coefficient of the Spearman rank-order correlation (r) takes the values of -1 and 1. A coefficient of +1 denotes that an improvement in one CSF results in an improvement in the correlated CSF and -1 denotes that an improvement in one CSF is associated with a decrease in the amount of the correlated CSF. The correlation analysis is often useful to identify correlated CSFs for factor analysis.

[**Table VI**. Correlation matrix of the CSFs for PPVC projects]

However, it also provides useful information for developing a conceptual framework of the CSFs. The implications of the correlation matrix (Table VI) is that most of the CSFs are mutually complementary and should be considered carefully in the management of the early stages of the PPVC project life cycle. Based on the correlation matrix, Figure 3 shows a conceptual framework for the management of the early stages of the PPVC project life cycle. The results in Table VI and the implications of Figure 3 are discussed in the next section.

Discussions of the CSFs for management of the early stages of PPVC projects

The mean, relativity, and significance indexes of the CSFs have revealed that the 9 CSFs are critical to the successful management of the early stages of PPVC projects. The conceptual framework (Figure 3) further shows how the early stages may be effectively managed to generate accurate drawings and timely design freeze. The results in the current study diverge significantly from the works of Li et al. (2018) on the critical success factors for planning and control of PHP in China. The top 5 CSFs in the current research are different from the top 5 CSFs in the works of Li et al. (2018). This highlights the sensitivities of the CSFs to project types and territories and makes a useful contribution to the management of the early stages of the PPVC project life cycle. Considering that all the CSFs are found to be significant and critical, they are discussed (in ranked order) in this section with references to the statistics in Table IV – VI and Figure 3. The CSFs are discussed according to their overall ranking in Table V.

[**Figure 3**. A conceptual framework of the CSFs for managing the early stages of PPVC projects]

CSF2 – Robust design specifications, accurate drawings, and early design freeze

This CSF was ranked first among the 9 CSFs with a mean score of 3.96, a relativity weight of 0.120, and a significance index of 79.29% (Table V). It has significant positive correlations with CSF3, CSF5, CSF6, CSF8, and CSF9, indicating that its effective implementation could improve the success of five other CSFs. The design of PPVC projects constitutes a significant stage in its implementations. Drawing on the concept of DfMA, the manufacturing and assembly of the volumetric modules are significantly influenced by the accuracy of the design (Building and Construction Authority, 2019). During the detailed design and engineering stages, allowable tolerances are specified for the factory production and on-site assembly of the modules to avoid a significant risk of dimensional and geometric variabilities (Enshassi et al., 2019; Shahtaheri et al., 2017). Errors at the design stage may result in the production of components which are not consistent with the overall scope of the project. Considering that the modules usually designed and produced to be used in a specific project, inaccuracy of the design may generate huge cost to account for the wrongly produced components. Accurate drawing and early design freeze is a CSF for management of the early stages because the next major stage (component manufacture) in the PPVC project life cycle (Figure 1) can only commence after the design freeze (Gibb and Isack, 2003). From Figure 3, this CSF may be effectively achieved through good working collaboration, information sharing, and the use of technologies such as building information modeling (Wuni and Shen, 2019b). There is the need for designers, client, engineers, fabricators, and contractors to collaborate and share information during this stage because a decision made at this stage affects the roles of these stakeholders in the subsequent stages of the PPVC project life cycle.

CSF1 – Good working collaboration, effective communication and information sharing among project participants

Information exchange and communication throughout the PPVC project life cycle is paramount, specifically through early involvement of the actors such as contractors, subcontractors, and engineers. It is therefore not surprising that CSF1 was evaluated as a very critical in the management of the early stages of the PPVC project life cycle. CSF1 was ranked 2nd among the 9 CSFs with a mean index of 3.86, a relative weight of 0.117, and significance index of 77.14% (Table V). During the conception, planning, and design stage of PPVC projects, the inputs of several project participants are required. Decisions made at this stage affect the roles of subsequent project participants in the PPVC project life cycle (Luo et al., 2019; Wuni et al., 2019; Wuni and Shen, 2019a). For instance, the detailed design and engineering specifications produced by the architects, designers, and engineers are to be used to manufacture the components by the fabricator (Wuni and Shen, 2019b, 2019a). On-site installation of building components has to be supervised by assembly contractors or project managers. Thus, collaboration and information sharing are crucial to ensure that participants in upstream stages understand the implications of decisions made at downstream stages. The collaboration further allows for ideas of the various participant to be leveraged to facilitate accurate drawings and early design freeze. This collaboration becomes even obligatory, where the design-build procurement approach is adopted (Wuni and Shen, 2019a).

CSF3 – Effective stakeholder management

This CSF was ranked 3rd among the 9 CSFs with a mean index of 3.77, a relative weight of 0.114, and significance index of 75.36% (Table V). CSF3 had a significant positive correlation with CSF1, CSF2, CSF6, CSF7, CSF8, and CSF9, indicating that the effective management of stakeholders at the earliest stages is associated with improvement in 6 other CSFs. Considering that the PPVC supply chain stages are linked and associated with multidisciplinary stakeholders with their unique goals and value systems (Luo et al., 2019; Wuni et al., 2019), the effective management of the involved stakeholders at their early stages would facilitate the successful implementation of the PPVC project. Wuni and Shen (2019b) identified CSF3 as a critical success factor for implementing MiC projects, and Luo et al. (2019) found CSF3 to be a success factor in prefabricated construction projects.

CSF5 – Extensive project planning and scheduling

Extensive project planning and scheduling (CSF5) was ranked 4th out of the 9 CSFs with a mean index of 3.71, a relative weight of 0.112, and a significance index of 74.29% (Table V). From Table VI, CSF5 has significant positive correlations with CSF2, CSF6, and CSF8. From Figure 3, it constitutes one of the earliest project management activities in the PPVC project life cycle and may be effective through early engagement of designers, engineers, fabricators, and contractors. After a decision has been made to implement PPVC in a project, the planning team is required to identify and meet with key project stakeholders, set and prioritize the goals of the project, define deliverables, create the PPVC project schedules, plan for risk, and generate a project plan. This will allow the client or developer to recognize the early completion associated with PPVC projects (Choi et al., 2016; O'Connor et al., 2014) and to determine the adequacy of resources to support the rapid project schedule (Choi et al., 2016).

CSF9 – Early engagement of players such as designers, engineers, fabricators, and contractors

Early engagement of designers, architects, engineers, fabricators, and contractors is the most cited CSF for management of the early stages of PPVC project life cycle (Building and Construction Authority, 2017; Construction Industry Council, 2018). The concept of "early" used throughout the research emphasizes the early commitment and decision-making required to realize significant gains from PPVC projects. CSF9 was ranked 5th out of 9 CSFs for management of the early stages of the PPVC project life cycle with a mean index of 3.70, a relativity index of 0.112, and a significance index of 73.93. CSF9 was reported as a critical success factor for modular integrated construction (Wuni and Shen, 2019b) and PHP (Li et al., 2018). It has significant correlation with CSF2, CSF3, CSF6, and CSF7. Rentschler et al. (2016) argued that engaging the fabricators at the design stage is necessary because they sometimes have the best design ideas. Thus, these stakeholders should be given due consideration at the earliest stages.

CSF7 – Early advice and consideration from PPVC design and engineering experts

The effective implementation of PPVC requires a commitment to early planning and decision-making. Thus, the decision to implement PPVC must be made early from the outset of the project. CSF7 was evaluated as very critical in the effective management of the early stages of the PPVC project life cycle and ranked 6th out of 9 CSFs. It recorded a mean index of 3.66, a relativity index of 0.111, and a significance index of 73.21% (Table V). It has a significant positive correlation with CSF1, CSF3, and CSF6. The early advice from PPVC design and engineering experts is required to ascertain whether the design of the project is suitable for PPVC and the potential benefits associated with its implementation. Blismas et al. (2006) identified CSF7 as a critical early management activity to guide further decision and consideration of PPVC in a project. The early advice will facilitate the early commitment required to reap the full benefits of the PPVC technology.

CSF6 – Realistic feasibility analysis and early decisions

This CSF was ranked 7th out of 9 CSFs with a mean index of 3.55, a relativity index of 0.107, and a significance index of 71.07% (Table V). Realistic feasibility analysis is required to identify the practicality of implementing PPVC in a project. Economic analysis in the detailed feasibility study will inform PPVC investment decision (Hwang et al., 2018; Murtaza et al., 1993; Wuni and Shen, 2019a) and inform the early decisions and commitment to the PPVC approach in a project (Blismas et al., 2006). Wuni and Shen (2019a) explained that not all conditions and circumstances render PPVC the best construction approach for a project. Thus, realistic feasibility assessment and systematic economic analysis will provide a sound basis for making the early decisions to implement PPVC in a project. This will further allow for early commitment to be made at the outset of the PPVC project to realize the maximum benefits of the approach. The implication is that bespoke feasibility analysis must be conducted at the earliest stages to ascertain the feasibility of implementing PPVC in the project and the associated cost and benefits.

CSF8 – Adequate experience and technical knowledge of key participants

PPVC is a disruptive technology which requires different capabilities and technical knowledge of the key project participants (Fraser et al., 2015). For instance, some amount of manufacturing knowledge and skills is required to evaluate the detailed design of the project. It is not surprising that adequate experience and technical knowledge of the key participants (CSF8) was evaluated as very critical in the management of the early stages of the PPVC project life cycle. This CSF was ranked 8th out of 9 CSFs with a mean score of 3.50, a relativity weight of 0.106, and a significance index of 70.00% (Table V). Considering the significant importance of the design stage to the entire PPVC project life cycle (Figure 1), the engineer or designer must have adequate experience and technical knowledge to deliver accurate designs and robust engineering specification for manufacturing of the building components. Errors made in the design could hatch a huge risk of cost increase in the form redesign, remanufacturing of components, dimensional and geometric variabilities, and site-fit reworks (Wuni et al., 2019). Thus, the key project participants should have enough knowledge to deliver the early stages with infinitesimal errors.

CSF4 – Effective use of information and communication technology (e.g., BIM)

Information and communication technologies constitute one of the disruptions in the construction industry, which are changing how construction projects are planned, designed, and managed. One of such disruptive tools is building information modeling (BIM). BIM is a tool which can promote deeper collaboration and efficient coordination of the multidisciplinary stakeholders in the PPVC project life cycle (Mostafa et al., 2018). Effective use of information and communication technology such as BIM was evaluated as a critical CSF for management of the early stages of the PPVC project life cycle. CSF4 was ranked 9th and last of the CSFs with a mean index of 3.38, a relativity weight of 0.102, and a significance index of 67.50%. The use of BIM at the earliest would provide a common digital platform to coordinate the views and ideas of the different project participants into the design of the PPVC project. The key participant can see the changes made to the design in real-time and could improve the design significantly. Where circumstances merit, BIM should be adopted at the early stages to facilitate deeper and closer collaboration among the client, designers, architects, engineers, fabricators, and contractors. This will improve the effective management of the stakeholders (Luo et al., 2019; Wuni et al., 2019; Wuni and Shen, 2019b).

Conclusions, contributions, and limitations

The success of PPVC projects is directly linked to the key decisions made at the earliest stages of the project life cycle. However, knowledge of how best to manage the early stages of the PPVC project life cycle is limited. This research evaluated the CSFs required for effective management of the conception, planning, and design stages of the PPVC project life cycle. The research adopted a quantitative research design where an online-based structured questionnaire was used to measure the significance of identified CSFs for management of the early stages of PPVC projects. The research collected data from international PPVC experts distributed across 18 countries and six continents who have substantial research and hands-on experience in different PPVC project types. Based on mean score analysis, relativity weightings and significance indices, the experts evaluated all 9 CSFs as critical in the effective management of the early stages of the PPVC project life cycle. Of the 9 CSFs, the top 5 most significant CSFs include *robust design specifications, accurate drawings and early design freeze*; *good working collaboration, effective communication and information sharing among project participants*; *effective stakeholder management at the early stages*; *extensive project planning and scheduling*; and *early engagement of key players such as designers, architects, engineers, fabricators and contractors*. This research constitutes the first exclusive quantitative evaluation of the CSFs required for management of the early stages of the PPVC project life cycle and has both theoretical and practical implications for the management of PPVC projects. Theoretically, the research has established an exclusive checklist of CSFs required for management of the early stages of a PPVC project life cycle. Practically, the study has identified and ranked the CSFs, which should be given sustained attention and resources commitment to improving the success of PPVC projects. Overall, the study will improve the practice and praxis of PPVC project management. However, the study suffered the following limitations: (1) although adequate, the sample size was small, and hence the results may suffer from the limited sample; (2) the study adopted a generic approach to the assessment of the CSFs, but the CSFs are sensitive to project types and territories. Therefore, bespoke studies are required prior to implementation of a PPVC project. Future studies will develop a structural equation model of the CSFs, exploring their interactions and interdependences.

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Table I. Potential CSFs for PPVC projects (Wuni and Shen, 2019b)

Code	Potential CSFs for PPVC projects
CSF1	Good working collaboration and effective communication
CSF2	Effective supply chain coordination and management
CSF3	Clear specifications, accurate drawings, and early design freeze
CSF4	Involvement of key players throughout the project
CSF5	Suitable procurement strategy and contracting
CSF6	Effective use of information and communication technology
CSF7	Extensive project planning and scheduling
CSF8	Feasibility and economic analysis
CSF9	Early advice and consideration from PPVC experts
CSF10	Adequate experience and technical knowledge of key participants
CSF11	Early engagement of designer, fabricator, and contractor
CSF12	Effective risk management
CSF13	Effective stakeholder management

Table II. Final list of CSFs for management of the early stages of the PPVC project life cycle

Code	Potential CSFs for PPVC projects
CSF1	Good working collaboration, effective communication and information sharing among project participants
CSF2	Robust design specifications, accurate drawings, and early design freeze
CSF3	Effective stakeholder management
CSF4	Effective use of information and communication technology (e.g., BIM)
CSF5	Extensive project planning and scheduling
CSF6	Realistic economic analysis and early decisions
CSF7	Early advice and consideration from PPVC design and engineering experts
CSF8	Adequate experience and technical knowledge of key participants
CSF9	Early engagement of key players such as designers, engineers, fabricators, and contractor

Table III. Background information of the PPVC experts

Attribute	Sub-attribute	Responses	% Responses
Job Sector	Academia	44	78.6
	Industry	12	21.4
	Total	***56***	***100.0***
Years of PPVC work experience	Below 5 years	27	48.2
	5 - 10 years	13	23.2
	11 - 15 years	5	8.9
	16 - 20 years	2	3.6
	21years and above	9	16.1
	Total	***56***	***100.0***
Country	United States	10	17.9
	Canada	8	14.3
	China	7	12.5
	Hong Kong	7	12.5
	Australia	5	8.9
	Malaysia	4	7.1
	United Kingdom	4	7.2
	Brazil	1	1.8
	Finland	1	1.8
	Germany	1	1.8
	Greece	1	1.8
	Lebanon	1	1.8
	Singapore	1	1.8
	Slovakia	1	1.8
	Spain	1	1.8
	Sweden	1	1.8
	Switzerland	1	1.8
	Tanzania	1	1.8
	Total	***56***	***100.0***

Table IV. Shapiro – Wilk and Kruskal – Wallis tests results of the CSFs

Code	CSF for PPVC projects	Frequency of ratings					Shapiro – Wilk Test (Sig.)	Kruskal – Wallis test (Asymp. Sig)
		1	2	3	4	5		
CSF1	Good working collaboration, effective communication and information sharing among project participants	0	2	16	26	12	0.000*	0.534
CSF2	Robust design specifications, accurate drawings, and early design freeze	0	3	10	29	14	0.000*	0.931
CSF3	Effective stakeholder management	0	5	13	28	10	0.000*	0.605
CSF4	Effective use of information and communication technology (e.g., BIM)	1	6	25	19	5	0.000*	0.708
CSF5	Extensive project planning and scheduling	0	6	15	24	11	0.000*	0.958
CSF6	Realistic feasibility analysis and early decisions	0	7	18	24	7	0.000*	0.239
CSF7	Early advice and consideration from PPVC design and engineering experts	0	10	10	25	11	0.000*	0.453
CSF8	Adequate experience and technical knowledge of key participants	0	6	21	24	5	0.000*	0.108
CSF9	Early engagement of key players such as designers, engineers, fabricators, and contractor	1	2	21	21	11	0.000*	0.816

*The Shapiro–Wilk test was significant at the 0.05 significance level, indicating the data were not normally distributed

Table V. Mean, relativity and significance indices of the CSFs for PPVC projects

Code	CSF	Mean index	Standard deviation	Relativity index	Significance index (%)	Ranking
CSF2	Robust design specifications, accurate drawings, and early design freeze	3.96	0.81	0.120	79.29	1
CSF1	Good working collaboration, effective communication and information sharing among project participants	3.86	0.80	0.117	77.14	2
CSF3	Effective stakeholder management	3.77	0.85	0.114	75.36	3
CSF5	Extensive project planning and scheduling	3.71	0.91	0.112	74.29	4
CSF9	Early engagement of key players such as designers, engineers, fabricators, and contractor	3.70	0.89	0.112	73.93	5
CSF7	Early advice and consideration from PPVC design and engineering experts	3.66	1.00	0.111	73.21	6
CSF6	Realistic feasibility analysis and early decisions	3.55	0.87	0.107	71.07	7
CSF8	Adequate experience and technical knowledge of key participants	3.50	0.81	0.106	70.00	8
CSF4	Effective use of information and communication technology (e.g., BIM)	3.38	0.86	0.102	67.50	9

Table VI. Correlation matrix of the CSFs for PPVC projects

Code		CSF1	CSF2	CSF3	CSF4	CSF5	CSF6	CSF7	CSF8	CSF9
CSF1	r	1.000								
CSF2	r	0.269*	1.000							
CSF3	r	0.395**	0.435**	1.000						
CSF4	r	0.105	0.224	0.045	1.000					
CSF5	r	0.110	0.363**	0.188	0.002	1.000				
CSF6	r	0.249	0.408**	0.298*	0.112	0.387**	1.000			
CSF7	r	0.382**	0.243	0.477**	0.071	0.185	0.518**	1.000		
CSF8	r	0.301*	0.430**	0.524**	0.073	0.275*	0.561**	0.500**	1.000	
CSF9	r	0.210	0.276*	0.376**	0.234	-0.012	0.314*	0.309*	0.232	1.000

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

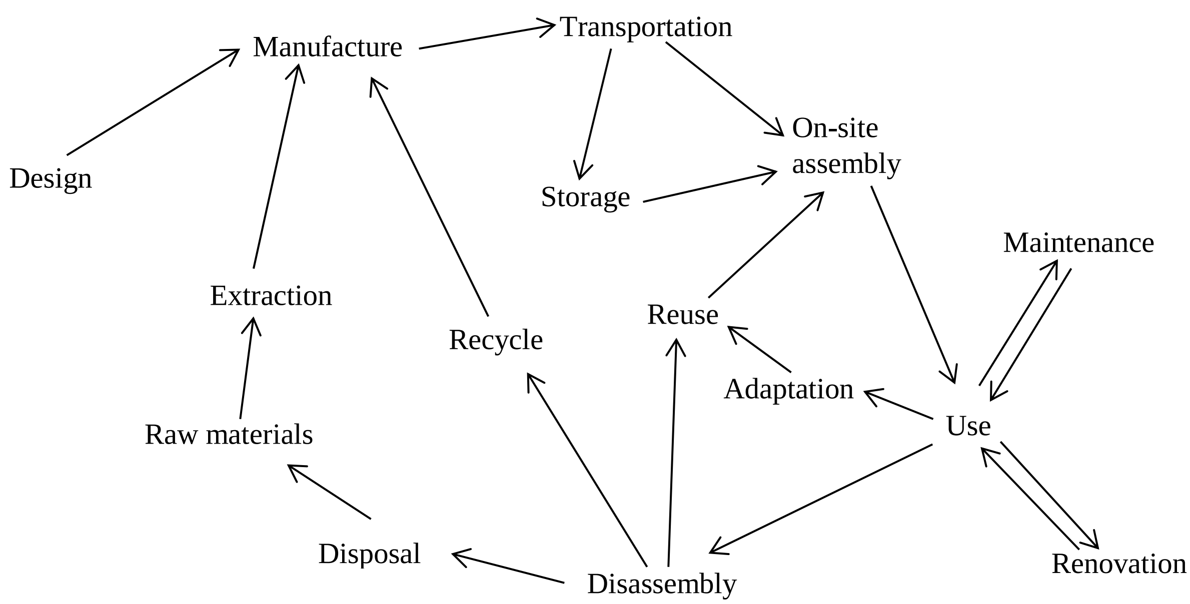

Figure 1. The basic life cycle of a PPVC project

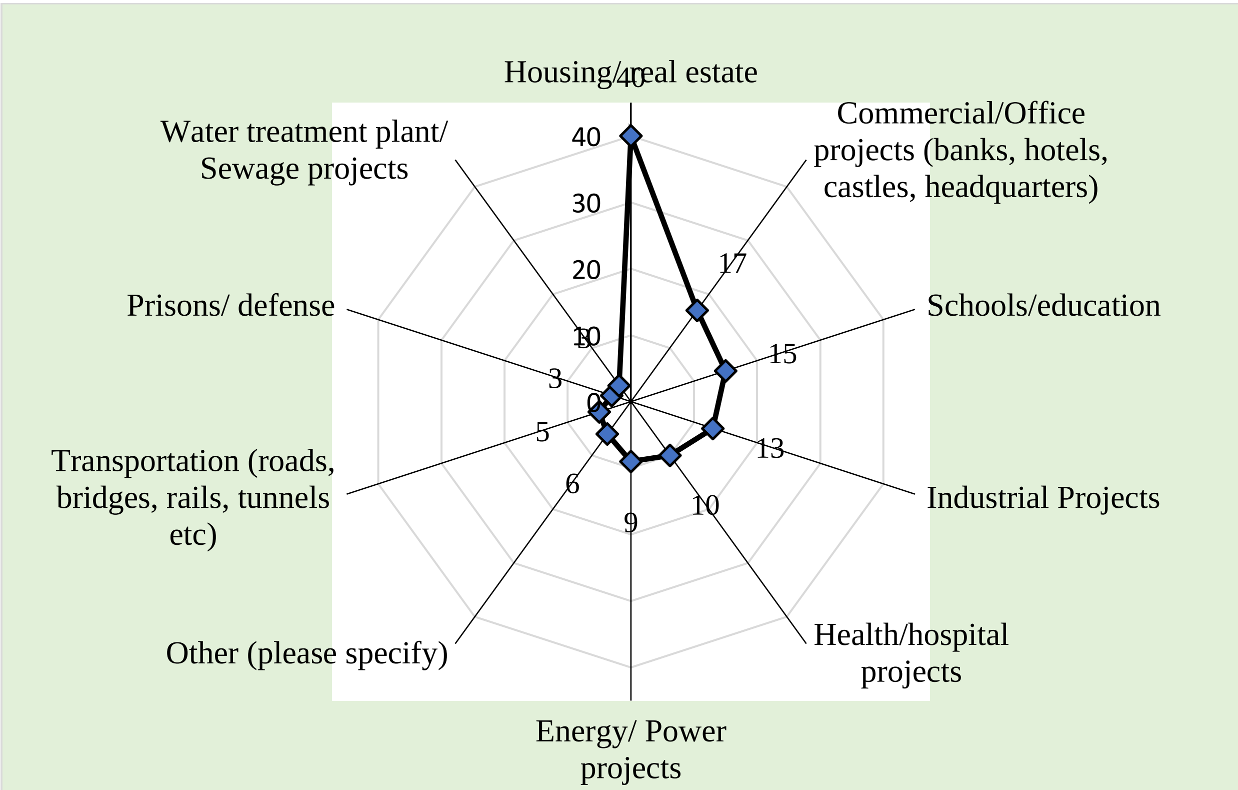

Figure 2. PPVC project types associated with the experiences of the experts

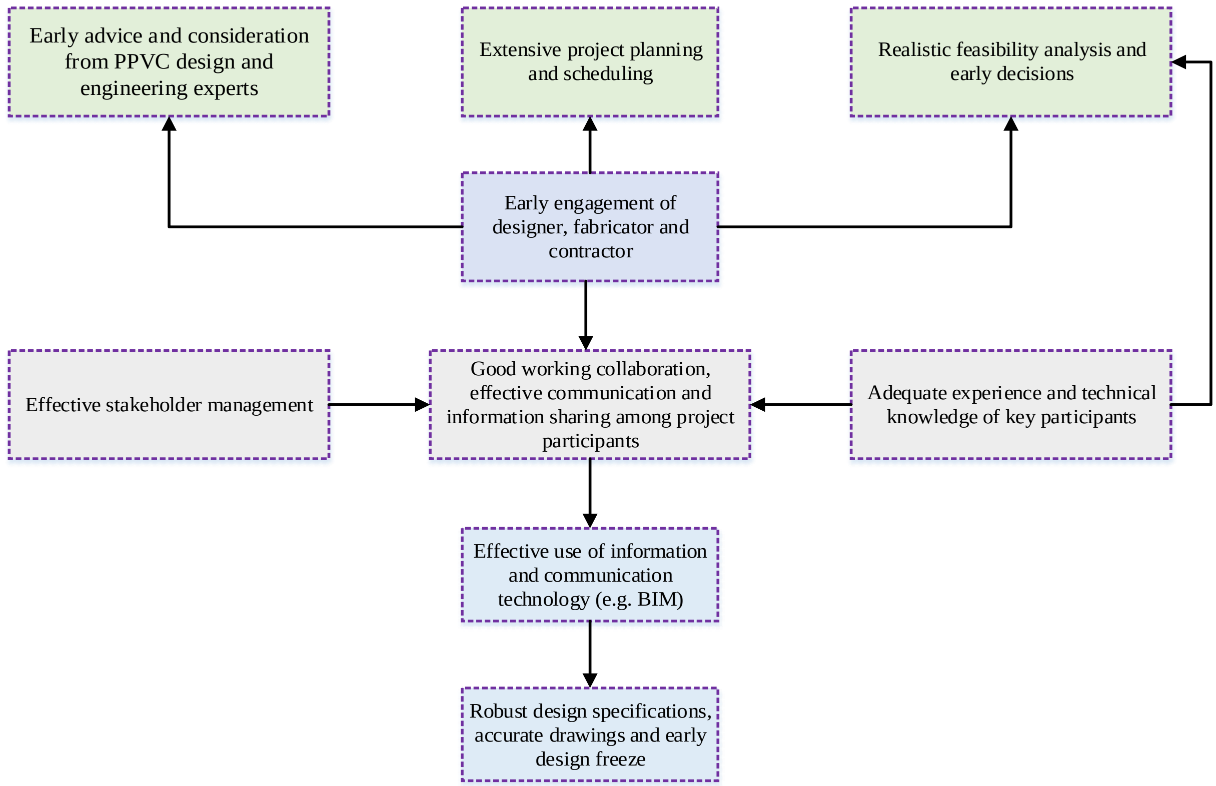

Figure 3. A conceptual framework of the CSFs for managing the early stages of PPVC projects