Prefabricated Prefinished Volumetric Construction: Key Constraints and Mitigation Strategies

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Abstract. Prefabricated prefinished buildings (PPVC) is a more innovative and cleaner way to reorganize production in the construction industry. Although the application of PPVC has been well received over the past few decades, the limitations of using PPVC have not been explored. Therefore, the purpose of this study is to investigate the main factors influencing the adoption of PPVC and propose a set of feasible mitigation strategies to address these factors. To achieve these goals, a comprehensive literature review was conducted first, followed by a structured questionnaire survey of 41 Singapore construction organizations. The analysis showed that the top five major limiting factors and found the top three most effective mitigation strategies. This study contributes to the knowledge system by studying the constraints and mitigation strategies of PPVC. At the same time, the results of this study also have some implications for the industry to understand and implement PPVC better.

1. Introduction
Prefabricated prefinished volumetric construction (PPVC) is a characteristic approach with high efficiency in off-site construction methods in which building elements, components, and modules will be manufactured and assembled in off-site factories and then they are transported to site for installation [1]. Even though PPVC has been widely recognized by construction industry worldwide, up to now, it’s still in the start-up stage. A great deal of knowledge about PPVC is still unmined. Therefore, the purpose of the investigation is to search out significant constraints in adopting PPVC in construction projects as well as existing buildings, and to put forward a set of mitigation strategies which contribute to resolve these constraints. In addition, this study is also beneficial to the study of knowledge system of off-site construction study, particularly for the study of PPVC. At the same time, this study concluded the experience and lessons of PPVC project in real life, which is of significance to industry practitioners that want to adopt PPVC.
2. Background

2.1 Prefabricated Prefinished Volumetric Construction in Singapore
On the basis of the definition of BCA[2], PPVC is a kind of construction method in which independent volume modules (including finishes for walls, floors and ceiling) are manufactured and assembled in approved manufacturing facilities in the light of any approved manufacturing method and then transported to the site for installation to form a building. Unlike the traditional continuous construction methods of design, engineering and construction activities, PPVC can greatly accelerate the implementation of the project, thus improving the productivity [3]. Lately, PPVC has been popular around the world. Since 2010, Singapore's BCA has launched two rounds of the construction productivity roadmap (round 1 in 2010 and round 2 in 2015), for the aim of promoting prosperity in the local construction industry [4].

2.2 The Adoption of PPVC: Constraints and Mitigation Strategies
Literature review reveals that several studies have made outstanding achievements in concluding the limitations, challenges, obstacles and constraints of general off-site construction methods. For instance, Mao et al. [5] conducted a questionnaire survey to investigate the main obstacles hindering the adoption of off-site construction methods in Chinese construction industry. Eventually, 18 constraints that may impede the adoption of PPVC were extracted from the literature review, as shown in table 1.

| Code | Constraints |
|------|-------------|
| C1   | Declined flexibility for future design changes |
| C2   | Unsupportive decision made by designers |
| C3   | Design restrictions because of traffic limitation (e.g. modules’ size) |
| C4   | Limited site distribution (e.g. lack of space for PPVC modules to be stored, unloaded and moved) |
| C5   | Less experiences design about PPVC |
| C6   | Less installation experiences about PPVC |
| C7   | Requirement for extra materials to protect PPVC modules |
| C8   | Added logistics and transportation considerations |
| C9   | Transportation restrictions due to rules and regulations |
| C10  | Less awareness of PPVC’s benefits among owners/developers |
| C11  | Raised organizational demand (e.g. changes in the roles of project participants) |
| C12  | Need for early commitment |
| C13  | Requirement for extra project planning and design efforts |
| C14  | More communication requested before and during construction |
| C15  | Expensive initial costs of traditional construction method |
| C16  | Expensive construction cost of the traditional construction method |
| C17  | Requirement of more communication among all stakeholders |
| C18  | Complicated process for inspection |

In order to solve the above limitations, challenges, and obstacles, a variety of mitigation strategies have been put forward. For example, plenty of studies put forward to apply information technologies such as BIM, three-dimensional visualization, and product information model to solve these information barriers met with in implementing off-site construction projects. According to a literature review, there are totally 9 mitigation strategies determined to help deal with the constraints related to PPVC, and they are compiled in table 2.
Table 2. Mitigation Strategies for the Constraints on Using PPVC

| Code | Mitigation Strategy                                                                 | Targeted Constraint       |
|------|-------------------------------------------------------------------------------------|---------------------------|
| MS1  | Encouraging project stakeholders to collaborate closely in early period of project   | C1, C2, and C3            |
| MS2  | Applying for temporary occupational permits (TOL) to build temporary sites           |                           |
|      | near construction sites to overcome site layout limitations                          | C4                        |
| MS3  | Apply of Just-in-Time delivery                                                      |                           |
| MS4  | Providing project teams and workers with training sessions to enhance the skills     |                           |
|      | and knowledge                                                                       | C5, C6, and C7            |
| MS5  | Fabricating and assembling the module components closely to the                     |                           |
|      | construction site to decrease transportation workload                               | C8 and C9                 |
| MS6  | Using Information Technologies (e.g. electronic file transfer) to overcome the       |                           |
|      | additional demand of planning, coordination and communication                        |                           |
|      | C10 and C11                                                                          |                           |
| MS7  | Conducting feasibility study on PPVC method                                          | C12, C13, C14, C15, C16, C17, and C18 |
| MS8  | Developing systems/computer programs for detailed economic analysis of PPVC          | C12, C13, C14, C15, C16, C17, and C18 |
|      | and conventional construction methods                                                |                           |
| MS9  | Applying BIM to promote coordination and increase communication among               |                           |
|      | project stakeholders                                                                 | C12, C13, C14, C15, C16, C17, and C18 |

3. Methods and Data Presentation

3.1 Data Collection and Presentation

This study adopted a variety of qualitative and quantitative research methods such as literature review, pilot interview and questionnaire survey. In the study of construction engineering and management (CEM), interviewing experienced industry experts is a great chance for a research to absorb meaningful opinions from practice [7]. Therefore, after the literature review, the study conducted preliminary interviews with industry experts to verify the limitations and mitigation strategies determined in the literature review. We invited three experienced industry experts in local PPVC projects to conduct pilot interviews for this research. They are senior members of the architectural innovation group. After that, this research adopts questionnaire survey to collect professionals' cognition of limitations and mitigation strategies. According to the results of the preliminary interview, a questionnaire was prepared. It was made up three parts, including the first part which recorded the respondents' background about their employer type and years of experience in construction and PPVC, the second part requiring respondents to use a five-point system (1 to 5 present different level of insignificance, 1 is the lowest level and 5 is the significance level, and so on), and the third part requesting respondents to use another 5-point scale (1 to 5 present different level of efficiency, 1 is the lowest level and 5 is the highest level, and so on). The research determined 100 institutions with prefabricated engineering experience in Singapore as potential respondents and sent them questionnaires via email to collect data. Eventually, 41 respondents were received, showing a response rate of 41%.

3.2 Data Analysis Methods

This study carried out statistical test and analysis on the questionnaire survey data. Parametric statistical test and non-parametric statistical test are two popular statistical tests at present [8]. Firstly, the normality of data should be checked in data analysis. If the p-value of the test is less than the selected alpha level (e.g., 0.05), then rejecting the null hypothesis and concluding that the test data is not normally distributed
In this research, an ordinary alpha level of 0.05 was adopted. Meanwhile, SPSS statistical 17.0 was employed for the test. Since the respondents come from all kinds of institutions, it’s necessary to make inter-group comparisons to see if there are significant differences in the respondents' views on institutions. ANOVA and Kruskal-Wallis test were used for comparison between groups. Therefore, the normality of the data presented by the Shapiro-Wilk test will decide the method to use for inter-group comparison.

Finally, constraint/mitigation strategies were compared in pairs to determine the most important constraints as well as the best mitigation strategies in PPVC.

4. Results and Discussions

4.1 Significant Constraints on Adopting PPVC

Table 3 and table 4 show the respondents’ evaluation of constraints and the results of statistical tests. The results of Shapiro-Wilk test in table 3 present that the constraint data are non-normal distribution. Thus, Kruskal-Wallis test was chosen for inter-group comparison, while Wilcoxon signed-rank test was employed for variable comparison. Results of Kruskal-Wallis test in table 3 indicate that, except for C7 "Requirement for extra materials to protect PPVC modules", all constraints have no significant difference in the respondents' institutional backgrounds. Such results mean that the respondents' evaluations are basically consistent and can be analyzed as a whole. At the same time, the evaluation results indicated in table 4 that C14 "More communication requested before and during construction", C13 "Requirement for extra project planning and design efforts", C8 "Added logistics and transportation considerations", C12 "Need for early commitment", and C15 “Expensive initial costs of traditional construction method”. In addition, according to Wilcoxon signed-rank test results in table 4, C14 and C13 were statistically higher than most constraints, indicating that they were the most important constraints when adopting PPVC.

In addition, in table 3, the sign “*” present that the Shapiro-Wilk test was significant at the significance level of 0.05, indicating the data was non-normal distribution, while “**” the Kruskal-Wallis test was significant at the significance level of 0.05, indicating statistical difference among respondents from different institutions. In table 4, the sign “*” The Wilcoxon Signed-Ranks test was significant at the significance level of 0.05, indicating the two compared variables were statistically different.

Table 3. Evaluations and Statistical Test Results of Constraints

| Code | Constraint                                                                 | Mean | Rank | Shapiro-Wilk test (p-value) | Kruskal-Wallis test (p-value) |
|------|---------------------------------------------------------------------------|------|------|----------------------------|-------------------------------|
| C14  | More communication requested before and during construction               | 4.37 | 1    | 0.000*                     | 0.344                         |
| C13  | Requirement for extra project planning and design efforts                 | 4.27 | 2    | 0.000*                     | 0.810                         |
| C8   | Added logistics and transportation considerations                          | 4.10 | 3    | 0.000*                     | 0.153                         |
| C12  | Need for early commitment                                                 | 4.00 | 4    | 0.000*                     | 0.162                         |
| C15  | Expensive initial costs of traditional construction method                | 3.95 | 5    | 0.000*                     | 0.054                         |
| C3   | Design restrictions because of traffic limitation (e.g. modules’ size)     | 3.94 | 6    | 0.000*                     | 0.677                         |
| C1   | Declined flexibility for future design changes                            | 3.93 | 7    | 0.000*                     | 0.403                         |
| C9   | Apply of BIM to improve coordination and facilitate communication among project stakeholders | 3.80 | 8    | 0.000*                     | 0.381                         |
| C4   | Limited site distribution (e.g. lack of space for PPVC modules to be stored, unloaded and moved) | 3.78 | 9    | 0.000*                     | 0.499                         |
Expensive construction cost of the traditional construction method

Requirement of more communication among all stakeholders

Complicated process for inspection

Less awareness of PPVC’s benefits among owners/developers

Less experiences design about PPVC

Less installation experiences about PPVC

Unsupportive decision made by designers

Requirement for extra materials to protect PPVC modules

Raised organizational demand (e.g. changes in the roles of project participants)

**Table 4. The Results of Constraints in Wilcoxon Signed-Ranks Test**

|     | C14 | C13 | C8  | C12 | C15 | C3  | C1  | C9  | C4  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C14 | -   | 0.285 | 0.100 | 0.050 | 0.028* | 0.056 | 0.014* | 0.006* | 0.016* |
| C13 | -   | 0.213 | 0.114 | 0.065 | 0.133 | 0.031* | 0.021* | 0.014* |
| C8  | -   | 0.715 | 0.399 | 0.516 | 0.382 | 0.058 | 0.154 |
| C12 | -   | 0.701 | 0.911 | 0.526 | 0.315 | 0.306 |
| C15 | -   | 0.987 | 0.809 | 0.325 | 0.466 |
| C3  | -   | 0.813 | 0.305 | 0.287 |
| C1  | -   | 0.498 | 0.474 |
| C9  | -   | 0.967 |
| C4  | -   | -   |
| C16 | -   | -   |
| C17 | -   | -   |
| C18 | -   | -   |
| C10 | -   | -   |
| C5  | -   | -   |
| C6  | -   | -   |
| C2  | -   | -   |
| C7  | -   | -   |
| C11 | -   | -   |

|     | C14 | C17 | C18 | C10 | C5  | C6  | C2  | C7  | C11 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C14 | 0.002* | 0.001* | 0.000* | 0.001* | 0.001* | 0.000* | 0.000* | 0.000* | 0.000* |
| C13 | 0.006* | 0.001* | 0.000* | 0.001* | 0.000* | 0.000* | 0.000* | 0.000* | 0.000* |
| C8  | 0.053 | 0.039* | 0.002* | 0.004* | 0.005* | 0.001* | 0.006* | 0.000* | 0.000* |
| C12 | 0.157 | 0.073 | 0.027* | 0.009* | 0.007* | 0.014* | 0.032* | 0.000* | 0.002* |
| C15 | 0.040* | 0.231 | 0.009* | 0.027* | 0.024* | 0.014* | 0.012* | 0.000* | 0.001* |
| C3  | 0.248 | 0.247 | 0.018* | 0.035* | 0.029* | 0.013* | 0.036* | 0.001* | 0.010* |
| C1  | 0.211 | 0.344 | 0.024* | 0.066 | 0.019* | 0.015* | 0.029* | 0.000* | 0.005* |
| C9  | 0.699 | 0.802 | 0.147 | 0.145 | 0.167 | 0.083 | 0.615 | 0.081 | 0.643 |
| C4  | 0.709 | 0.725 | 0.164 | 0.192 | 0.172 | 0.099 | 0.227 | 0.023* | 0.129 |
| C16 | -    | 0.837 | 0.319 | 0.230 | 0.283 | 0.213 | 0.124 | 0.016* | 0.070 |
| C17 | -    | 0.323 | 0.397 | 0.243 | 0.154 | 0.301 | 0.003* | 0.081 |
| C18 | -    | 0.962 | 0.815 | 0.656 | 0.578 | 0.049* | 0.535 |
| C10 | -    | 0.922 | 0.631 | 0.615 | 0.081 | 0.643 |
| C5  | -    | 0.790 | 0.868 | 0.025* | 0.863 |
| C6  | -    | 0.973 | 0.179 | 0.867 |
C2  -  0.240  0.990
C7  -  0.140
C11 -

4.2 Effective Mitigation Strategies for Constraints

Table 5 and table 6 revealed the respondents' assessment of the proposed mitigation strategy and the related statistical test results. As shown in table 5, the results of Shapiro-Wilk test were non-normal data distribution, so inter-group comparison and variable comparison will choose Kruskal-Wallis test and Wilcoxon Signed-Ranks test. Kruskal-Wallis test presented that all mitigation strategies except MS1 were evaluated unanimously by respondents, indicating that respondents had basically the same views on mitigation strategies. The evaluation results in table 5 mean that MS1, MS9 and MS4 are the top three effective mitigation strategies to tackle PPVC constraints. Furthermore, the Wilcoxon signed-rank test results in table 6 show that evaluation of MS1, MS9, and MS4 are statistically higher than most mitigation strategies, meaning that they are the best mitigation strategies for PPVC constraints. Meanwhile, the meanings of “*” and “**” in table 5 are same with those in table 3, and the implication of “*” in table 6 is same with that in table 4.

| Code | Mitigation Strategy                                                                 | Mean | Rank | Shapiro-Wilk test (p-value) | Kruskal-Wallis test (p-value) |
|------|-------------------------------------------------------------------------------------|------|------|----------------------------|-------------------------------|
| MS1  | Encouraging project stakeholders to collaborate closely in early period of project   | 4.17 | 1    | 0.000*                      | 0.046**                       |
| MS9  | Applying BIM to promote coordination and increase communication among project stakeholders | 4.07 | 2    | 0.000*                      | 0.437                         |
| MS4  | Providing project teams and workers with training sessions to enhance the skills and knowledge | 4.02 | 3    | 0.000*                      | 0.544                         |
| MS3  | Apply of Just-in-Time delivery                                                      | 3.68 | 4    | 0.000*                      | 0.684                         |
| MS5  | Fabricating and assembling the module components closely to the construction site to decrease transportation workload | 3.63 | 5    | 0.000*                      | 0.310                         |
| MS6  | Using Information Technologies (e.g. electronic file transfer) to overcome the additional demand of planning, coordination and communication | 3.63 | 6    | 0.000*                      | 0.839                         |
| MS8  | Developing systems/computer programs for detailed economic analysis of PPVC and conventional construction methods | 3.63 | 7    | 0.000*                      | 0.673                         |
| MS7  | Conducting feasibility study on PPVC method                                          | 3.56 | 8    | 0.000*                      | 0.316                         |
| MS2  | Applying for temporary occupational permits (TOL) to build temporary sites near construction sites to overcome site layout limitations | 3.46 | 9    | 0.001*                      | 0.425                         |

Table 6. The Results of Mitigation Strategies in Wilcoxon rank test

| MS1 | MS9 | MS4 | MS3 | MS5 | MS6 | MS8 | MS7 | MS2 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| -   | 0.381 | 0.568 | 0.005* | 0.014* | 0.002* | 0.003* | 0.001* | 0.001* |
| MS9 | -   | 0.741 | 0.046* | 0.039* | 0.006* | 0.007* | 0.001* | 0.004* |
| MS4 | -   | 0.112 | 0.055 | 0.043* | 0.030* | 0.008* | 0.012* |
| MS3 | -   |     | 0.826 | 0.777 | 0.717 | 0.562 | 0.292 |

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5. Conclusions and Recommendations

The literature review and empirical management investigation of industry experts was conducted. This study determined 18 important constraints (e.g., "previous extensive coordination requirements and construction period"), which hinder the adoption of PPVC. Besides, nine mitigation strategies to cope with constraints were proposed.

Even though the goal of this study has been achieved, there are still some limitations. First of all, the study collected subjective views of respondents according to their experience. Secondly, the sample quantity of questionnaire survey was not large enough. Finally, the results of this research can only be applied in Singapore, while it is not suitable for other countries. Nevertheless, the results of this research are still beneficial to the knowledge system, since they are the first to investigate the constraints as well as mitigation strategies of the PPVC methods. In addition, results of the research can provide the industry with a comprehensive understanding of the limitations and mitigation strategies of PPVC methods, thus benefiting the industry. In the future, it’s necessary to conduct economic analysis on PPVC and to test the key risks and the influences on project aims when adopting PPVC methods.

6. References

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