Journal of Cleaner Production 183 (2018) 183–193

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Key constraints and mitigation strategies for prefabricated prefinished volumetric construction

Bon-Gang Hwang [a], Ming Shan [b, *], Kit-Ying Looi [c]

[a] Department of Building, National University of Singapore, 4 Architecture Drive, 117566, Singapore
[b] School of Civil Engineering, Central South University, 68 South Shaoshan Road, Changsha, 410075, China
[c] Quantity Surveyor, Arcadis Singapore Pte. Ltd., 1 Magazine Road, #05–01 Central Mall, 059567, Singapore

ARTICLE INFO

Article history:
Received 3 October 2017
Received in revised form
30 January 2018
Accepted 13 February 2018
Available online 14 February 2018

Keywords:
Prefabricated prefinished volumetric construction
Prefabrication
Off-site construction
Constraints
Mitigation strategies
Singapore

ABSTRACT

Prefabricated prefinished volumetric construction (PPVC) is an innovative and cleaner approach that has restructured the production of the construction industry. It can improve the workflow continuity, increase the efficiencies in the use of resources, minimize construction wastes, and reduce the number of on-site contractors as well as construction durations. While the benefits of PPVC have been widely recognized over past two decades, the constraints on using PPVC remains unexplored. As a result, the aims of this study are to investigate the significant constraints demotivating the adoption of PPVC and to propose a group of feasible mitigation strategies to tackle these constraints. To achieve these goals, a comprehensive literature review was conducted first, followed by a structured questionnaire survey administered to 41 Singapore-based construction organizations. Lastly, an in-depth case study was conducted to verify the empirical findings. The analysis results showed that the top five significant constraints were "extensive coordination required prior to and during construction", "need for additional project planning and design efforts", "increased transportation and logistics considerations", "requirement for early commitment", and "higher initial cost than conventional construction method." It also revealed the top three most effective mitigation strategies: "encouraging close collaborations between project stakeholders during the early phase of the project", "use of BIM to improve coordination and facilitate communication among project stakeholders", and "offering training courses for project team and workers to enhance their knowledge and skills". This study contributes to the body of knowledge by examining the constraints and mitigation strategies for the adoption of PPVC. Also, the findings from this study are informative to the industry practitioners to have a better understanding and implementation of PPVC.

1. Introduction

Off-site construction is a process that manufactures and assembles building elements, components, and modules in off-site factories and then transports them to site for installation (Goodier and Gibb, 2007; Pan and Goodier, 2012). It is a cleaner and innovative construction approach that can improve workflow continuity and productivity (Li et al., 2016b; Mao et al., 2016), minimize construction wastes (Arashpour et al., 2016), reduce the number of on-site trade contractors (Jaillon and Poon, 2008), and reduce construciton durations (Arashpour et al., 2015). With its numerous benefits, off-site construction has been highly recognized by the global construction community and widely used by the construciton industries in many countries and regions, such as Hong Kong (Chiang et al., 2006), Spain (Pons and Wadel, 2011), Australia (Mostafa and Chileshe, 2017), Singapore (Wu and Low, 2012), the United Kingdom (Taylor, 2010), and the United States (O'Connor et al., 2014; Song et al., 2005).

According to the degree of the off-site work undertaken for product, off-site construction methods can be divided at different levels including component and subassembly, non-volumetric preassembly, volumetric preassembly, and modular construction (Gibb, 1999; Pan and Goodier, 2012). Among these various methods, prefabricated prefinished volumetric construction (PPVC) is a typical and efficient one. In PPVC projects, modules complete with finishes for walls, floors, and ceilings are built and manufactured in

* Corresponding author.
E-mail addresses: bdghbg@nus.edu.sg (B.-G. Hwang), bdgshanming@163.com (M. Shan), looi.kitying@arcadis.com (K.-Y. Looi).

https://doi.org/10.1016/j.jclepro.2018.02.136
0959-6526/

off-site factories (mostly 85–90 percent of the project work) and then transported to construction site for installation (Arif and Egbu, 2010; Kamali and Hewage, 2017; Mao et al., 2016). This method is particularly suitable for the built structures with repetitive design features, such as hotels, apartments, student residence, hospitals, and prisons (Mao et al., 2016). PPVC has multiple advantages. Unlike conventional construction methods where works are executed in a consecutive manner, PPVC allows works to proceed concurrently, which can shorten of the construction schedule significantly. Meanwhile, as PPVC allows the modules to be manufactured in off-site factories, it can also provide the workers with a pleasant working environment (Mao et al., 2015; Pan et al., 2007, 2012).

Being a city-state with limited natural resources and labor supply (Gao and Low, 2014), Singapore spares no effort in chasing productivity in its various industries, particularly in the local construction industry which is highly labor intensive (Ling et al., 2013; Pang and Lim, 2015). Currently, the Building and Construction Authority (BCA) of Singapore is exploring every viable alternative to enhance construction productivity, which includes PPVC (Lim, 2016b; Ministry of National Development (2016)). In the view of BCA, PPVC is a game-changing technology catering to the prevailing concept of Design for Manufacturing and Assembly, and also a revolutionary construction method able to achieve a significant productivity improvement. As such, in 2014, PPVC became selectively mandatory for built structures that are developed on the land released by the government, according to the regulations issued by BCA (BCA, 2017b).

Although it has been widely accepted by the global construction community, so far, PPVC is still in its infancy. Much of the knowledge regarding PPVC remains unexplored. As a result, this study aims to explore the significant constraints that limit the adoption of PPVC in existing building and construciton projects and to propose a group of mitigation strategies that can help address these constraints. Although there has been considerable research on offsite construction currently (e.g., Arashpour et al., 2016; Arif and Egbu, 2010; Goodier and Gibb, 2007; Johnsson and Meiling, 2009; Mao et al., 2015; Taylor, 2010), few of them looked into PPVC. Thus, this study can contribute to the body of knowledge of offsite construction research, especially focusing on PPVC. Meanwhile, as this study summarized the lessons and experiences learned from the real-life PPVC projects, it is also useful and informative to the industry practitioners who plan to adopt PPVC method, thereby benefiting their practices.

2. Background

2.1. Prefabricated prefinished volumetric construction

According to the definition of BCA (2017b), PPVC is a construction method whereby free-standing volumetric modules (complete with finishes for walls, floors, and ceilings) are manufactured and assembled in an accredited fabrication facility in accordance with any accredited fabrication method, and then transported to site and installed to form a building. Different from conventional construction methods in which design, engineering, and construction activities are consecutive, PPVC allows works to be done in parallel. Thus, it can help expedite the implementation of the project significantly and thereby increase productivity (Saad, 2016). Moreover, PPVC can result in tangible cost savings due to the less manpower and equipment required onsite compared to traditional construction methods (Bernstein et al., 2011). Furthermore, by carrying out the majority of the work in a controlled, factory environment, PPVC is able to provide a healthier and safer working environment for workers, which also addresses the safety concern of construction projects successfully (Mills et al., 2015). Although PPVC receives some criticisms that its overuse will make buildings lose aesthetic values in terms of individuality, uniqueness, and personality (The Business Times, 2016), its advantages are predominant and make itself a revolutionary method benefiting the construction industry (Lim, 2016a).

Recently, PPVC has become popular worldwide. In the US, a growing number of colleges and universities are using PPVC to build quick and convenient dormitories and classrooms. As estimated by Gregor (2008), PPVC can save the colleges and universities five to ten percent of construction costs and speed up the construction process at the same time. In Australia, there has been a growing trend that hotels are built using PPVC. This is because PPVC can ensure the construction of the hotels on schedule, and meanwhile the cheap construction costs allow hotels to offer their guests a high end hotel experience at a more affordable rate, enhancing their competitiveness (Waters, 2017). In the UK, an increasing number of homebuilders have launched prefab home divisions to build PPVC homes which are complete with light fittings, bathrooms, bookshelves and kitchens. Also, these homebuilders recognize PPVC a good strategy to tackle the challenge in labor, namely a shortage of skilled construction workers caused by an ageing workforce and an exodus due to Brexit (Booth, 2017). Furthermore, PPVC homes are becoming increasingly common in Japanese urban areas, due to improvements in design and quality, speed and compactness of onsite assembly, as well as due to lowering costs and ease of repair after earthquakes (Zhang, 2015).

2.2. PPVC in Singapore

Since 2010, BCA of Singapore has launched two rounds of Construction Productivity Roadmap (1st in 2010 and 2nd in 2015) aiming to improve the productivity in local construction industry (Navaratnarajah, 2016). Particularly, in the 2nd Construction Productivity Roadmap BCA highlighted that prefabrication would be one of the main directions that the local construction industry should go forward (Lim, 2016a). Recently, BCA has been promoting PPVC actively. For example, BCA stipulated that the adoption of PPVC method was one of the land sale conditions for some selected land parcels sold under the Government Land Sales Program from 1 November 2014 (BCA, 2017b). Subsequently, in 2015 BCA further stipulated that for the developments of these selected land parcels, the minimum level of use of PPVC should be 65 percent of the total constructed floor area (including all floors except the basement and any floor area built for use as a roof or car park) (BCA, 2015). Moreover, BCA has set up an acceptance framework to certify each PPVC supplier and manufacturer to make sure the different PPVC systems used at mandated development sites are reliable and durable, (BCA, 2017b). In addition to BCA, the Housing and Development Board (HDB) of Singapore is another local authority have interest in PPVC (Lim, 2016a). HDB deems PPVC as a productive and helpful instrument for its HDB apartment development. HDB is currently carrying out some research initiatives to develop an integrated, automatic PPVC production system (Lim, 2016a). To sum up, under the enthusiasm from the local authorities, PPVC is being actively advocated and promoted in Singapore.

2.3. The adoption of PPVC: constraints and mitigation strategies

Given the limited amount of research, the constraints to the adoption of PPVC and the relevant mitigation strategies can hardly be extracted from the existing literature directly. However, there is considerable documentation on generic off-site construction methods in current literature, which is also applicable to PPVC to a certain extent. Thus, this study conducted a comprehensive