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Knowledge-based decision support system for prefabricated prefinished volumetric construction

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ABSTRACT

As prefabricated prefinished volumetric construction (PPVC) has gained considerable attention worldwide in the past few years, decision-making for implementing PPVC becomes critical. As a result, this study aims to (1) identify the key decision-making factors (DMFs) for the adoption of PPVC, (2) propose a scoring approach that can assess the feasibility of using PPVC for a given project, and (3) develop a Knowledge-Based Decision Support System for Prefabricated Prefinished Volumetric Construction (KBDSS-PPVC) that can facilitate the decision-making for PPVC implementation. To achieve these goals, a comprehensive literature review and pilot interviews with industry experts were conducted first, followed by a structured questionnaire administered to 41 construction organizations in Singapore. Results of the questionnaire reported 19 DMFs of PPVC, which were then used to create the PPVC scoring approach. Subsequently, the KBDSS-PPVC was developed using the created PPVC scoring approach. Lastly, a panel of industry experts validated the developed KBDSS-PPVC, by utilizing the tool for their current construction projects. Validation results showed that the developed system could provide reliable recommendations for the industry practitioners on the decision-making of PPVC. Existing literature has seldom addressed the decision-making of PPVC, therefore, this study bridges the knowledge gap and contributes to the current body of knowledge. Furthermore, the developed KBDSS-PPVC would be useful to the industry practitioners as well, because it can help them achieve a better and easier decision-making of PPVC.

1. Introduction

Off-site construction refers to a process where building elements, components, and modules are manufactured and assembled in off-site factories and then transported to site for installation [1,2]. Compared to traditional construction approaches, off-site construction is more innovative and clean because it can improve the continuity and productivity of workflow significantly [3, 4], minimize the construction wastes [5], reduce the number of on-site trade contractors [6], and reduce construction durations [7]. Given the numerous benefits, off-site construction has been highly recognized by the global construction community in recent years. The process has been widely used by construction industries in many countries and regions, such as Hong Kong [8], Spain [9], Australia [10], Singapore [11], China [12,13], the United Kingdom [14], and the United States [15,16].

Prefabricated prefinished volumetric construction (PPVC) is a typical off-site construction method. It is a production process where modules complete (nearly 85–90%) with finishes for walls, floors, and ceilings are built and manufactured in off-site factories first and then transported to the construction site for installation [4,17,18]. Unlike conventional construction methods that are often executed in a consecutive manner, PPVC allows works to proceed concurrently. Therefore, it can reduce the construction schedule significantly. Furthermore, as PPVC allows the modules to be manufactured in off-site factories, it can also provide the workers with a pleasant working environment [19]. This method is particularly suitable for built structures with repetitive design features, such as hotels, apartments, student residences, hospitals, and prisons [4].

In view of its significant benefits, developers and contractors have become increasingly interested in PPVC and the possibility of its implementation in their projects [20,21]. However, prior to making the decision, developers and contractors need to examine the compatibility of PPVC and their projects. This study focuses on the decision-making for PPVC in building and construction projects. In this context, there are three questions that warrant consideration. First, what are the key decision-making factors (DMFs) for adopting PPVC in building and construction projects? This study hypothesizes that there are some particular DMFs for PPVC, which are different from those for general off-site

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Table 1
Potential DMFs of PPVC.

No.	Potential DMF	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Suitability of design for modularization						√						√	√						
2	Presence of repetitive layout in design						√				√		√	√						
3	Number of stories										√									
4	Building exterior type										√									
5	Structural stability of individual and assembled modules		√										√			√				
6	Need for inspection/supervision of manufacturing units		√										√			√				
7	Lead time for fabricated modules		√										√			√				
8	Module's size	√	√													√				
9	Site accessibility				√	√	√	√		√	√		√	√						
10	Transportation equipment availability	√	√		√	√		√						√						
11	Construction equipment availability	√	√		√	√		√						√						
12	On-site labor availability	√	√	√		√		√		√			√		√		√		√	√
13	Labor cost at site location			√		√		√		√		√		√	√		√	√	√	√
14	Availability of production information, skilled workforce and experienced team		√	√		√	√	√		√				√	√	√	√		√	√
15	Availability of experienced labor force in factory environment	√	√	√		√	√	√		√				√	√	√	√		√	√
16	Site location					√		√						√	√	√				
17	Availability of manufacturing plants/facilities within economical transport distance		√			√		√							√	√	√			
18	Organization's familiarity with PPVC	√	√										√				√		√	
19	Early involvement of top management	√	√										√				√		√	
20	Use of information and communication technology (e.g., BIM)									√			√							
21	Size and type of project	√								√					√					
22	Need for expediting the schedule		√	√	√		√						√			√				√
23	Overall project timescale		√	√	√		√			√					√	√				√
24	Certainty of project completion date		√	√	√	√		√	√						√	√				√
25	Certainty of project cost		√	√	√	√		√		√		√			√	√	√	√		√
26	Minimizing labor and plant cost on site		√	√	√		√			√		√			√	√	√	√		√
27	High standard quality of both internal and external finishes of building		√	√	√	√		√	√	√					√					√
28	Reduction in defects of product/facility		√	√	√					√					√					√
29	Improved construction safety		√			√		√	√	√					√					√
30	Reducing environmental impact through the reduction of site activities		√			√		√	√						√				√	√
31	Reducing neighborhood disruption and noise		√			√		√							√				√	√
32	Reducing traffic movement to/from site which cause less neighborhood pollution and congestion		√			√		√							√				√	√

Note: A = Construction Industry Institute [46]; B = Murtaza, et al. [34]; C = Gibb and Isack [37]; D = Blismas, et al. [47]; E = Pan, et al. [38]; F = Tam, et al. [45]; G = Pan, et al. [39]; H = Scofield, et al. [48]; I = Chen, et al. [35]; J = McGraw Hill [49]; K = Pan and Sidwell [30]; L = Azhar, et al. [41]; M = Rahman [43]; N = Elnaas [50]; O = Zhai, et al. [36]; P = Mao, et al. [12]; Q = Lee and Kim [51]; R = Liu, et al. [52]; S = Wong, et al. [40].

Table 2
DMFs affecting the adoption of PPVC method.

Code	Decision-making factors
DMF1	Suitability of design for PPVC
DMF2	Presence of repetitive layout in design
DMF3	Number of stories
DMF4	Structural stability of individual and assembled modules
DMF5	Need for inspection/supervision of manufactured units
DMF6	Lead time for PPVC modules
DMF7	PPVC module's size
DMF8	Site layout (e.g. availability of storage space for PPVC modules/ availability of sufficient space to unload)
DMF9	Site location
DMF10	Availability of skilled labor and experienced supervising team
DMF11	Availability of transportation equipment
DMF12	Availability of construction equipment
DMF13	Organization's familiarity with PPVC method
DMF14	Use of information and communication technology (e.g. BIM)
DMF15	Size and type of the project (i.e. project scope)
DMF16	Shorter construction duration at site
DMF17	Improved construction safety
DMF18	Reducing environmental impact through the reduction of site activities
DMF19	Reducing neighborhood disruption and noise

Table 3
Profile of the respondents.

Respondent Profile	Frequency	Percentage (%)	Cumulative Percentage (%)
Respondent's Institution			
Governmental agency	1	3	3
Developer	5	12	15
Construction company	21	51	66
Consultancy	6	15	81
Architectural firm	3	7	88
Quantity Surveyor	2	5	93
PPVC Supplier/ Manufacturer	3	7	100
Respondent's occupation			
Architect	4	10	10
Engineer	13	32	42
Project Manager	7	17	59
Quantity Surveyor	9	22	81
Facility Manager	8	19	100
Years of experiences in the construction industry			
1–4 years	16	39	39
5–9 years	7	17	56
> 10 years	18	44	100
Years of experiences with PPVC projects			
< 1 year	27	66	66
2 years	9	22	88
3 years	5	12	100

construction methods. Second, how would these factors affect the decision-making of PPVC? Third, is it possible to develop a convenient, computer-aided tool for industry practitioners to facilitate their decision-making of PPVC? To answer these questions, this study identified the key decision-making factors (DMFs) affecting the use of PPVC, proposed a scoring approach that could assess the feasibility of using PPVC for a given project, and developed a Knowledge-Based Decision Support System for Prefabricated Prefinished Volumetric Construction (KBDSS-PPVC).

This research study was conducted in the context of Singapore. Being a city-state with a limited working age population [22], Singapore gives significant value to production approaches that require less