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AN ENTROPY-BASED STUDY ON THE EFFECTIVENESS OF PREFABRICATION IN ACHIEVING SUSTAINABLE CONSTRUCTION

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Prefabrication has been widely adopted in the construction projects in recent years. It has also been advocated as a greener and more sustainable approach of project delivery. However, with a wealth of evidence supporting other reasons as the drivers of using prefabrication, it is questionable whether the real goal of prefabrication is to achieve sustainable construction. This study aims to investigate the roles of prefabrication in fostering sustainable construction. The effectiveness of prefabrication on fostering sustainable construction was evaluated on the five aspects enlisted by the UK's Green Construction Board: Waste, Water, Carbon, Materials, and Biodiversity. An industry survey was conducted in Melbourne, Australia for data collection. 200 questionnaires were sent via email or post to a variety of fields within the construction industry. Entropy ranking analysis was adopted to analyze the effectiveness of using prefabrication in construction. The results suggest that prefabrication is effective in reducing construction waste and sourcing energy efficient materials. However, the utilization of prefabrication was found unsuccessful in reducing carbon emissions during the construction process. It is suggested that proactive actions should be taken at the design stage to unleash the potential of prefabrication in construction.

Keywords: Prefabrication, Sustainable construction, Effectiveness, Entropy analysis.

1 INTRODUCTION

Prefabrication can be defined as the completion of substantial parts of construction works prior to their installation on-site (Blismas *et al.* 2006). It was mainly applied in producing precast concrete components like facades, staircases, partition walls and slabs (Gibb 1999). This situation did not change until recent years when the advancement of building information modeling, 3-dimensional printing and volumetric preassembly technologies unleashed the potential of a more extensive use of prefabrication in construction projects (Pan *et al*. 2012). The advancement of prefabricated technology greatly reduces on-site assembly time as compared to conventional construction methods. Fully manufactured building facilities including; Bathroom pods, kitchen pods and modular units are now possible to be manufactured off-site (Jaillon and Poon 2014). By adopting more radical methods, completely finished modular buildings can be factory made and, once complete, transported to site for installation on a developed substructure (Lu 2007). The aforementioned methods reduce the requirements for skilled on-site labor associated with in-situ construction.

Other benefits of greater reliance on prefabrication have also been extensively reported (Blismas *et al.* 2006). These include optimizing integration between planning and design, improving end product quality control and improving site safety (Nadim and Goulding 2010). Interestingly, in recent years, researchers also advocated prefabrication as the effective means of achieving sustainable construction (Osmani *et al.* 2006). Aye *et al.* (2012) conducted an embodied carbon estimate and justified that prefabrication as a better alternative in regard to embodied energy savings. Based on a questionnaire survey conducted in the United Kingdom, Osmani *et al.* (2006) revealed that prefabrication fosters sustainable construction by reducing construction wastes and encouraging proactive planning for greener designs.

While some researchers advocated the use of prefabrication as a more sustainable option, ironically other literatures indicate that perhaps getting rid of laborers and reducing construction time are the true motives for pushing prefabrication forward (Blismas *et al.* 2006). The mix findings reported above make it interesting to investigate the effectiveness of prefabrication in achieving sustainable construction. This study helps provide insight into choosing appropriate strategy to achieve sustainable construction. This helps address how prefabrication can be truly embraced as one the effective strategies to achieve such goal. The study reported in this paper aims to investigate the effectiveness of prefabrication on fostering sustainable construction. The proceeding sections of this paper are organized as follows. Firstly, the measures of evaluating the effectiveness of prefabrication in sustainable construction are identified. Secondly, the research methodologies of this study are presented. Finally, the findings and its implications are discussed.

Table 1. Evaluators of effectiveness of prefabrication in achieving sustainable construction (adopted from Green Construction Board 2015).

Aspects	**Respective Operational Statements:-** *Implementing prefabrication in your project is effective to achieve the following goals:*	
Waste	WS1-	Waste minimization during the design and construction phase of the project
	WS2-	Enable greener designs to be established that create less waste
	WS3-	Limit the amount of packaging used to protect material
	WS4-	Allow for the recycling of previously used materials to thus avoid landfill
Water	WT1-	Allow for water targets to be set to minimize water usage both during the construction and operation of the project
	WT2-	Reduce water consumption through the life of the project
	WT3-	Allow for water usage to be tracked during the construction phase
	WT4-	Prevent water pollution at during construction and operational life
Carbon	CB1-	Allow for carbon targets to be set to monitor effective performance
	CB2-	Reduce carbon emissions in the design process by taking into account the whole life of the project
	CB3-	Allow for carbon emissions to be cut during the construction and manufacturing stage
	CB4-	Enable carbon saving by giving occupants the ability to cut their carbon usage.
Materials	MT1-	Allow for new and more environmentally friendly materials to enter the market
	MT2-	Enable material to go further through more effective designs and resource efficiency
	MT3-	Have a low environmental impact whilst improving the performance of the project
	MT4-	Allow for the responsible sourcing of materials
Biodiversity	BV1-	Provide better results when paired with sites of low ecological and agricultural value
	BV2-	Enable the assessment and monitoring of natural habitat
	BV3-	Incorporate features such as green roofs and walls that are able to protect the environment
	BV4-	Benefit from consultations of specialists who can develop long term management plans that meet the needs for people and wildlife

2 IDENTIFYING EVALUATORS OF SUSTAINABLE CONSTRUCTION

The concept of sustainable construction has been described in different contexts (Kilbert 1994; Ding 2008; Miller *et al.* 2015). Kilbert (1994) described it as 'the creation and responsible maintenance of a healthy built environment, based on ecological principles, and by means of an efficient use of resources'. Miller *et al.* (2015) stated sustainable construction is generally about 'delivering development by any definition that appropriately and equally benefits economic and social considerations, while concurrently minimizing related environmental impacts'. Ding (2008) argued that the interpretation of sustainable construction varies depending on the parties involved. For instance, a building owner may view this from an economical viewpoint whereas an occupant may be more interested in the in-door quality and safety impacts of buildings. The above review indicates that the concepts of sustainable development and sustainable construction are sometimes mixed up (Green Construction Board 2015). Sustainable development, while being a globally used expression of idea, combines a range of environmental issues with socio-economic issues (Kilbert 1994). In contrast, sustainable construction focuses on how sustainability can be achieved throughout the building life cycle (Green Construction Board 2015). In this aspect, the United Kingdom's Green Construction Board (2015) conducted a comprehensive review and developed measures that evaluate the effectiveness of sustainable construction in five aspects: Waste; Water, Carbon, Materials and Biodiversity. This study adopts the work of Green Construction Board (2015) and proposes that the effectiveness of prefabrication in achieving sustainable construction can be evaluated under these five aspects. The related operational statements are outlined in Table 1.

3 THE RESEARCH METHODOLOGIES

Data was collected by way of questionnaire. The questionnaire designed for this study consists of two parts. Part 1 includes questions designed to solicit the respondents' demographic information. Part 2 of the questionnaire consists of the 20 operational statements as shown in Table 1 for evaluating the effectiveness of prefabrication in achieving sustainable construction. Respondents were asked to assess the degree of agreement of the statements by using a five-point Likert scale (from 1:"Strongly Disagree" to 5: "Strongly Agree"). Respondents targeted for this study are directors, project managers and professional grade staff from consultants, main contractors, sub-contractors and suppliers which are listed in the latest edition of builders' directories and the official web pages of the professional institutes. On random basis, 200 questionnaires were sent via e-mail to the respondents who are working in the greater Melbourne region in Australia. To assist evaluation, mean scores of the five aspects suggested by the Green Board Construction (2015) are compared: waste, water, carbon, materials, biodiversity. The aspects scores are computed using the Eq. (1):

$$F_i = \frac{\sum_{j=1}^{n} A_{ij}}{n} \tag{1}$$

Where F_i is the Aspect score, A_{ij} is the mean score of the j^{th} operational statement of Aspect i. For example, the Aspect score of "Waste" is computed as follows:
F_{waste} = [3.02 (WS1: Waste minimisation during the design and construction phase of the project) + 2.98 (WS2: Enable greener designs to be established that create less waste) + 3.41 (WS3: Limit the amount of packaging used to protect material) + 3.03 (WS4: Allow for the recycling of previously used materials to thus avoid landfill)] / 4 = 3.11.

Entropy ranking analysis is adopted to present in five major aspects the effectiveness of prefabrication in achieving sustainable construction. Entropy ranking analysis is a quantitative measure that compares the importance of the attributes in terms of their respective normalized weightings (Tang *et al.* 2012). Eq. (2) presents how priority ratings of the attributes can computed.

$$P_x = \frac{E_x}{e^{H_x}} = \frac{\sum_{i=l}^{n} S_i \cdot T_{mi}}{e \sum_{i=l}^{n} T_{mi} log_5(T_{mi})} \tag{2}$$

Where: P_x = Priority Rating of the operational statement (OS); E_x = Expected value of the OS; H_x = Entropy of the OS; i = A constant from 1 to n; S_i = scales of degree of significance; T_{mi} = probability of a scale; n = number of scales.

4 RESULTS AND DISCUSSIONS

A total of 200 questionnaires were sent to the identified respondents by e-mails. A total of 56 usable responses were used in the. The valid response rate, therefore, is 27%. Similar research study performed by Tang *et al.* (2012) had a sample size of 35. The sample size of this study is considered comparable to similar studies.

Among the five aspects suggested by the Green Construction Board (2015), 'Waste' received the highest mean at 3.30 out of 5. Second place was Materials (Mean = 3.02, S.D. = 0.92). The results indicate that the respondents generally agree that prefabrication is effective to achieve sustainable construction in terms of using more environmental friendly materials and waste reduction. However, mean scores of Water (Mean = 2.59, S.D. = 0.94), Carbon (Mean = 2.26, S.D. = 0.99) and Biodiversity (Mean = 2.12, S.D. = 0.85) are all lower than 3 on a 5-point Likert scale, this indicates that prefabrication may not be effective to achieve sustainable construction in these aspects. The results of Entropy ranking analysis further verify such findings (Table 2).

Those attributes related to Biodiversity (BV1 to BV4), Carbon (CB1 to CB4) and Water (WT1 to WT4) are ranked among the lowest. The results indicate that prefabrication is generally ineffective in reducing carbon emissions, water consumptions and maintaining the biodiversity of the environment. However, it is worth noting that previous studies that attempted to describe prefabrication as sustainable option usually focused on carbon reduction and water saving during the construction process (Jaillon and Poon 2014). Such assumptions failed to fully appreciate indirect embodied carbon emissions covering manufacture and transporting prefabrication units. Similar results were obtained when attributes of Biodiversity (BV1 to BV4) were tested, their almost the lowest normalized weightings and the low mean score indicate that prefabrication cannot effectively mitigate the ecological impact the construction project brings onto the environment. Indeed, a number of studies have already pointed out that despite construction practitioners might aware the negative impacts brought by the construction developments to the environment, they do not necessarily need to respond to the call from the governments and the societies to go green (Wong and Zapantis 2013).

The comparative high normalized weightings of WT1 to WT4 (ranged from 0.059 to 0.068 as shown in Table 2) indicate the ability to minimize waste as a key reason that cause prefabrication to be effective in sustainable construction. However, this may be due to the fact that the construction practitioners were concerned with the cost of construction waste disposal (Wong *et al.* 2015). However, on a positive note, attributes related to 'Materials' are seen to be the second most significant category behind 'Waste' through the entropy normalized weightings that are ranged from 0.055 to 0.059 (Table 2). The results perhaps indicate that the respondents see prefabrication as a tool to introduce new environmental friendly materials to enter the market that foster sustainable construction.

Table 2. Entropy rankings on effectiveness of prefabrication to achieve sustainable construction.

	Expected Value E_x	**Priority Rating P_x**	**Normalized Weighting**	**Entropy Ranking**
WS1-	3.59	3.49	0.068	1
WS2-	3.22	3.13	0.061	2
WS3-	3.11	3.03	0.059	4
WS4-	3.26	3.17	0.061	2
WT1-	2.50	2.43	0.047	12
WT2-	2.59	2.52	0.049	10
WT3-	2.57	2.50	0.048	11
WT4-	2.69	2.61	0.050	9
CB1-	2.46	2.39	0.046	13
CB2-	2.30	2.23	0.043	15
CB3-	2.33	2.27	0.044	14
CB4-	1.96	1.92	0.037	20
MT1-	3.15	3.05	0.059	4
MT2-	3.09	3.0	0.058	6
MT3-	2.91	2.82	0.055	7
MT4-	2.94	2.86	0.055	7
BV1-	2.02	1.96	0.038	19
BV2-	2.11	2.05	0.040	18
BV3-	2.15	2.08	0.040	18
BV4-	2.24	2.18	0.042	17

5 THE CONCLUDING REMARKS

Prefabrication has become a more popular construction alternative in recent years. However, prefabrication may not be adopted deliberately for sustainable construction purpose. Some studies pointed out that prefabrication can be an effective way to foster sustainable construction. The results of this study indicate that such perceptions may be valid in terms of reducing construction wastes and sourcing more environmental friendly materials to building prefabrication components. However, prefabrication might not be conducive to sustainable construction in terms of reducing carbon, water consumption as well as maintaining the biodiversity of the surrounding environment. With due caveats on the limitations of the sample size as well as the geographical constraints, this finding may be though provoking for those who believe prefabrication is a panacea for attain sustainable construction. The true motives of using prefabrication can be unrelated to sustainable construction. The findings of this study help the policy makers, practitioners and researchers to focus on the true motives that can foster sustainable construction more effectively.

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