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Cost analysis for sustainable off-site construction based on a multiple-case study in China

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ABSTRACT

Off-site construction (OSC) methods, such as prefabrication and modularisation have been regarded as an efficient way to boost sustainability and productivity against conventional cast-*in-situ* methods. Nevertheless, the promotion of OSC in many countries has lagged behind during the past 20 years because of the lack of explicit recognition with regard to the spending and savings associated with deploying such innovative methods in the construction industry. The multiple-case study method is applied to conduct an in-depth analysis on expenditure items of implementing OSC against conventional construction methods in China. Findings validate that the total cost of implementing OSC or semi-OSC techniques is significantly higher than that for conventional construction methods. The major expenses are incurred from such processes as prefabricated component production, transportation, and design consultancy. Compared with developed countries, the experience, skills, and market demand of applying OSC in China are far from adequate, which also increases the price of deploying OSC nationwide. By contrast, the spending of OSC on masonry, plastering, and measurement works is lower. Furthermore, a shift from on-site construction to factory-based indoor prefabrication decreases the number of workers required and the project delivery timeframe, thereby contributing to cost savings. To conclude, this study rationalises the wider adoption of OSC in the near future through comprehensive and thorough cost analysis case studies from which stakeholders in China would understand the pros and cons of OSC and eventually make deliberate decisions.

1. Introduction

Off-site construction (OSC) methods, such as prefabrication and modularization, have emerged as promising construction methods to address traditional *in-situ* construction challenges, such as productivity, logistics, safety, pollution, wastage, quality, and subjectivity to environment and weather (Blismas & Wakefield, 2009; Jaillon & Poon, 2008, 2009; Li et al., 2016; Mao, Shen, Shen, & Tang, 2013). For the global construction industry, prefabrication is not a new construction process, but one that has been used extensively and widely for many years. Given the numerous benefits of implementing OSC, a growing uptake of OSC has been witnessed in several countries and regions, such as Hong Kong, Singapore, the United Kingdom, and the United States. Since the mid-1980s, Hong Kong has adopted a policy to require prefabrication in public housing construction (Chiang, Chan, Lok, 2006; McCutcheon, 1990), and precast elements, reusable formwork, and modular design and assembly are extensively adopted in public housing projects; the private housing sector in Hong Kong is also attempting to keep abreast with this trend (HKBD, 2001). To reduce dependency on resources and imported workforce, Singapore is the first country to promulgate statutory provisions in which buildability, quality, and productivity are the three mandatory requirements for construction companies to achieve (Chiang et al., 2006). OSC may also help Singapore to overcome the skill shortage issues that are commonly observed in the constantly changing built environment and complex construction projects. Moreover, the prefabrication of a building would reduce lifecycle waste by 60% (Pons & Wadel, 2011). In the United Kingdom,

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prefabricating houses has not been commercially successful because of perceived barriers, such as high costs and a reduced space for the client and designer to personalise. However, recently completed prefabricated hotel, apartment, house, and sheltered accommodation projects have increased since the last decade, which thus portends a wider uptake in the near future. In the United States, the manufacturing and construction industries have made significant advances in implementing off-site processes to build and deliver more sophisticated and complex facility types through system prefabrication, modularization, and panelisation. Clients are starting to turn to off-site methods for multi-story wood construction, steel-framed structures, healthcare facilities, educational structures, and large-scale military projects (NIBS, 2016).

The Chinese construction n industry is experiencing a shift from traditional low-end labor-intensive projects to high-end technology-intensive projects. The construction sector in China continues to contribute a large percentage to the national gross domestic product. Hence, the focus of the central government of China on shifting the construction sector to a higher value-added and knowledge-intensive level via enhancing construction innovation capability has been transferred to higher quality, innovative products, and established business processes (Wang & Yuan, 2011). OSC is viewed as a technique to fulfill this target. Sustainability and environmental impact from construction are a genuine concern for China. These issues when coupled with the expertise of China in manufacturing are expected to take advantage of the benefits of OSC. However, the current scale of OSC in China remains lower than that of other regions and countries. As reflected from its projected market value, the OSC share of China remains below 2% of its entire construction sector (Li, 2015; NCRE, 2015). Several significant barriers that impede the use of OSC in China are as follows: constructability implementation by virtue of skills, experience, and knowledge; social climate and attitudes, such as market acceptance and demand; architectural performance, including design diversity, aesthetics, maintenance complexity, and quality impression; costing associated with initial cost, capital cost, and capital payback period; supply chain issues; lack of codes, standards, and government incentives; and strategic policies and regulations (Blismas & Wakefield, 2009; Kam, Alshawi, & Hamid, 2009; Mao, Shen, Pan, & Ye, 2013; Zhang, Skitmore, & Peng, 2014). To promote viable technological upgrade and reform to the traditional manner, extensive capital costs and complex interfacing between off-site and on-site components and systems are required (Dewick & Miozzo, 2002; Khalfan & Maqsood, 2014). The high initial costs associated with fixed assets, such as establishing fabrication factories and prefabricating building modules and components, as well as the concerns of mortgage lenders and insurers about the capital payback period of constructing non-traditional buildings, are collectively considered hindrances to a widespread undertaking of OSC in China (Mao, Shen, & Pan et al., 2013; Pan & Sidwell, 2011). Jaillon and Poon (2009) and Bhangale and Mahajan (2013) revealed that the high initial costs could be counteracted by improved productivity, reduced labor, early completed and defect-free deliverables, and the use of new materials, such as precast reinforced concrete planks and prefabricated brick panels. When confronting the paradox between OSC adoption and cost uncertainty, most Chinese stakeholders report a lack of available scientific or empirical studies that can help them justify an OSC or non-OSC option. As stated by Pan and Sidwell (2011), major dilemmas associated with information knowledge paucity involve the following: (1) the conceptual ambiguity of OSC costs, (2) the consequently real or perceived higher costs of off-site solutions than those of traditional options, (3) the lack of cost data and information on OSC, and (4) the unknown techniques of decreasing construction costs but increasing effectiveness. On this premise, this study generalises the following research gaps that hamper the deployment of OSC in Chinese construction projects:

- The ad-hoc costing items/categories rooted in OSC during the construction stage.
- The extent to which OSC could decrease costs as against traditional construction methods, and the possible justifications.

To fulfill the cost investigation and analysis, this study uses the multiple-case study method (MCSM) and identifies prefabricated concrete systems (PCSs) as the primary construction elements because PCS holds the largest market share in China. The remainder of this paper is divided into six sections. Section 2 presents the definition of OSC. Section 3 provides a critical review of the related literature, with a focus on the research gaps, together with a justification of methodology applied in this study. Section 4 discusses the cost analysis for implementing OSC. Section 5 presents the data derived from two case studies. Section 6 indicates the results and discussion. Finally, Section 7 concludes this study. The main conclusion is that increased recognition from costing synthesis has been gained to increase the confidence and commitment of stakeholders to OSC.

2. Overview of OSC

Similar to traditional on-site construction, OSC can be used to form a variety of architectures and functions, including residential and commercial buildings and infrastructure, such as power stations and oil and gas plants. OSC is typically implemented in manufacturing plants that are specifically designed for fabricating modular units. As stated in Table 1, OSC has several similar terms and interpretations. Gibb and Isack (2003) categorised the vast range of OSC or what they refer to as "pre-assembly" into four categories. The first and most traditional form is component manufacture and sub-assembly, which encompasses typical factory-made components, such as bricks and tiles. The second category is non-volumetric pre-assembly, which takes the level of OSC one step further by including semi-finished components, such as precast concrete slabs, structural insulated panels, prefabricated light steels, and PCSs. The third category is volumetric pre-assembly. This technique includes a pre-assembled unit, such as bathroom pods, kitchen pods, or plant rooms; usable spaces, which once delivered to the site require only installation into a steel or concrete-framed structure; and the connection of services (Arif & Egbu, 2010; Gibb & Isack, 2003). The fourth category according to Gibb and Isack (2003) is modular building, which refers to most of the construction effort being concentrated off site in a factory setting. Pre-assembled modules that form the actual structure and fabric of the building are then simply transported, assembled, and connected together on site. Arif and Egbu (2010) considered this classification further, suggesting a fifth hybrid category in which a combination of any two or more of the above could also exist.

3. Justifications of research gaps and methodology

While OSC is not a new concept, a number of issues have brought it into the spotlight. Cigolini and Castellano (2002) proposed a quantitative model to determine the cost variance between modular construction and stick built. Other studies have identified comprehensive criteria to aid the decision making of stakeholders with regard to OSC. For example, Pan, Dainty, and Gibb (2012) developed more than 50 value-based decision criteria and quantified their relative importance for systematically assessing building technologies. Landolfo, Fiorino, and Corte (2006) identified the most critical factors for selecting modularisation or stick built.