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Investigating waste reduction potential in the upstream processes of offshore prefabrication construction

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ABSTRACT

The construction industry around the globe has been increasingly advocated to utilize prefabrication to minimize waste, thereby alleviating associated negative impacts on environment and the society. Previous studies have reported on waste reduction potential from adopting prefabrication in various economies including Hong Kong. A significant shortcoming of these studies; however, is the neglect of the upstream processes of prefabrication including the manufacturing and transportation of components, which causes construction waste as well. To date it is still unclear how this portion of construction waste is generated and quantified. The issues are even more complicated in Hong Kong where components are manufactured in the offshore Pearl River Delta Region (PRDR) of mainland China and transported across the border to construction sites in Hong Kong. Against the theoretical backdrop of whole life cycle thinking, the aim of this study is to empirically investigate the manufacture and cross-border transportation processes, thereby to assess the waste reduction potentials of using prefabrication in construction. It does so by conducting three in-depth case studies with selected PRDR prefabrication factories. A hybrid of research methods are employed in the study. It is found that the waste generation rate in the upstream processes of offshore prefabrication is around 2% or lower by weight. This proves the orthodox that prefabrication in a factory environment is more conducive to waste reduction than the traditional cast in-situ construction manner. However, transporting the components adds cost and simultaneously increases the risk of waste generation. This study provides insights into understanding construction waste reduction through offshore prefabrication from a holistic view.

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1. Introduction

In spite of its significant contribution to built environment development, construction is also perceived as a contributor to the degradation of environment [1,40]. Amongst the many factors such as dust, greenhouse gas emissions, noise pollution and

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consumption of non-renewable natural resources, construction waste is a major culprit. For example, historically the UK construction waste consumed more than 50% of the overall landfill volume [15] and 70 million tons of construction waste was discarded annually [42]. Similarly, the US construction industry was reported to generate over 100 million tons of construction waste per annum [36] and approximately 29% of the solid waste in the USA was from the construction sector [41]. In Australia, construction activities generated 20–30% of all the waste entering landfills [13]. In Hong Kong, the latest statistics on solid waste ending up at landfills reached 13,458 t per day in 2011, of which 25% was construction waste [14]. Disposal of waste in landfills has led to extensive amounts of air, water and soil pollution due to the production of CO_2 and methane from anaerobic degradation of the waste [32,51].

How to minimize construction waste effectively has been a challenging issue receiving worldwide attention (e.g. [1,12,33,39,43,45]). Amongst the various waste management strategies, prefabrication has been increasingly advocated. Prefabrication refers to structures or components of structures prefabricated at a different location other than the construction site, e.g. individual modules of a building are made in a factory and then transported to construction sites for final assembly [17]. Sometimes, this is entitled “offsite construction” or “industrialized building”, an idea borrowed from manufacture, generally taking place at a specialized facility (e.g. an assembly line) in which various materials are combined to form a distinct component of a larger installation [7]. It has been commonly recognized that benefits of using construction prefabrication include reductions in cost, time, defects, health and safety risks, and a consequent increase in quality, predictability, whole-life performance and profitability [17,21,38,44,49].

Researchers have endeavored to ascertain the waste reduction potential of using prefabrication. For instance, Tam et al. [46] conducted one of the early studies in Hong Kong finding that construction waste could be minimized up to 84.7% if prefabrication is applied. Jaillon and Poon [26] conducted a comprehensive review of the evolution of prefabricated residential building systems in Hong Kong in both the public and private sectors. Their findings revealed a greater extent of prefabrication usage in terms of volumes and types of precast elements adopted. They also investigated the sustainable construction aspects (i.e., environmental, economic and social benefits) of using prefabrication in dense urban environment by taking Hong Kong as an example [25]. Specifically, they tried to quantify the waste reduction potential of using prefabrication in building construction in Hong Kong, and found that construction waste reduction is one of the major benefits when using prefabrication compared with conventional construction; the average wastage reduction level was reported to be approximately 52% when adopting prefabrication [27].

Nevertheless, by taking on-site components assembly as a point of departure, their research design omitted of the upstream processes of prefabrication including manufacture and transportation of precast components. They compared prefabrication with traditional cast in-situ construction without fully considering the upstream processes, or in other words, the “cradle-to-site” processes, which could also result in construction waste. It has been understood that construction waste from precast concrete manufacture could be reduced in a factory environment, but to what extent it is really achieved and how transportation and storage of the components induce construction waste is not clear. Such enquiries are probably more complicated in a setting where precast components are manufactured offshore (such as in the PRDR) and transported to remote construction sites (such as in Hong Kong). This is called offshore prefabrication, which is not unique in the Hong Kong – PRDR setting but has been widely practiced by firms in some advanced economies [28].

The aim of this study is to investigate the manufacture and cross-border transportation processes towards a life cycle assessment (LCA) of waste reduction potentials of using prefabrication construction. It allows a holistic understanding of waste management along the entire supply chain. Against a theoretical backdrop of LCA, this study conducted case studies in three medium-to-large scale PRDR prefabrication yards that supply precast components to Hong Kong. Although the study is undertaken in Hong Kong and the PRDR as a unique socio-economic background, there are similarities to other offshore supply chain settings such as Singapore–Malaysia, Europe–China, and the US–China.

2. Research methodology

Life cycle analysis (LCA) is a technique that has been widely used to evaluate the environmental impacts throughout a product's life cycle, ranging from raw material acquisition, production and use phases, to final waste disposal [22]. Finnveden et al. [16] pointed out that the comprehensive scope of LCA is useful in order to avoid problem-shifting, for example, from one phase of the life cycle to another, from one region to another, or from one environmental problem to another. LCA is thus considered an ideal approach for holistically assessing waste reduction potential throughout the whole process of offshore prefabrication. This resonates with European Commission Communication recommending that LCA methodology [23,24] should be used jointly with the waste hierarchy such as reduction, reuse, and recycling. Despite that the applications of LCA to the environmental assessment of municipal solid waste (MSW) management have been prolific (e.g., [2,5,10,29,30,37,48]), Mercante et al. [35] reported that LCA research in construction waste management is just beginning and not comparable with those reported in MSW management.

According to the ISO 14040 and 14044 standards, LCA is carried out in four distinct phases: (a) goal and scope definition; (b) life cycle inventory analysis; (c) impact assessment; and (d) interpretation. Owing to the sluggish development and erratic data availability in LCA of offshore prefabrication, this study focuses on the first two steps to define the goal and scope, and develop a flow model of the prefabrication system, based on which a more in-depth life cycle inventory analysis and impact assessment can be conducted accordingly by filling data when it is available. The study therefore must first draw a full picture of the supply chain of the offshore prefabrication for precast concrete components.

Three case studies were conducted to obtain data for describing offshore concrete prefabrication, with a view to identifying construction waste generated throughout the process. Case studies allow the exploration and understanding of complex issues based on primary data. It is considered a robust research method, particularly when a holistic and in-depth investigation is required Yin [50]. Under the umbrella of case study, various research methods such as interviews, focus group meetings, and participatory or non-participatory observations can be organized in a systematic way to understand the issue under study. In the PRDR there are nine sizable prefabrication yards that are mainly responsible for supplying precast concrete components to Hong Kong (see Table 1). Most of them are subsidiaries set up by main contractors or construction clients operating in Hong Kong. These yards provide internal supply to their parent companies. Two case studies were conducted from companies listed in Table 1 and one case study was carried out in a smaller company that supplies both the Hong Kong and PRDR construction markets. In each case, 3–7 researchers were involved. The studies started with interviews with senior personnel in each company. A semi-structured open-ended discussion approach was used. A total of 8 questions (see Table 2) were presented and addressed in each of the interview