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Waste generated in high-rise buildings construction: A quantification model based on statistical multiple regression

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ABSTRACT

Reducing construction waste is becoming a key environmental issue in the construction industry. The quantification of waste generation rates in the construction sector is an invaluable management tool in supporting mitigation actions. However, the quantification of waste can be a difficult process because of the specific characteristics and the wide range of materials used in different construction projects. Large variations are observed in the methods used to predict the amount of waste generated because of the range of variables involved in construction processes and the different contexts in which these methods are employed. This paper proposes a statistical model to determine the amount of waste generated in the construction of high-rise buildings by assessing the influence of design process and production system, often mentioned as the major culprits behind the generation of waste in construction. Multiple regression was used to conduct a case study based on multiple sources of data of eighteen residential buildings. The resulting statistical model produced dependent (i.e. amount of waste generated) and independent variables associated with the design and the production system used. The best regression model obtained from the sample data resulted in an adjusted R^2 value of 0.694, which means that it predicts approximately 69% of the factors involved in the generation of waste in similar constructions. Most independent variables showed a low determination coefficient when assessed in isolation, which emphasizes the importance of assessing their joint influence on the response (dependent) variable.

1. Introduction

Construction and demolition waste account for a large share of all solid waste generated worldwide. The reduction of the high rate of losses in construction sites, which includes waste materials and debris, is one of the main challenges faced by this sector (Poon, 2007). Waste generation has different environmental perspectives: firstly, it increases the consumption of construction materials, in addition, if these materials are not properly managed, they may create a soil and water contamination hazard (Agopyan and John, 2011).

The guidelines for waste management focus primarily on eliminating the generation of waste (i.e. the adoption of processes that do not produce waste). A secondary approach consists of reusing, recycling, recovering and ultimately ensuring that the waste produced is properly disposed (European Commission, 2008).

Yuan et al. (2012) highlight the role of government regulations: the introduction of higher charges for construction waste disposal and recycling practices incentive a strong economic way for developers and contractors to implement measures to reduce construction waste.

In this context, some countries have reported promising results. In the case of Japan, the amount of construction waste dropped from 99 million tons to 77 million tons in a ten-year period (1995–2005), while the recycling rate increased from 58% to 92% in the same period (CIB, 2011). The Netherlands, Denmark, Germany and the UK show construction waste recycling rates ranging between 50% and 90% (Ângulo, 2005). According to Baldwin et al. (2009), the government of Hong Kong will soon run out of landfill spaces and public disposal areas and has recently introduced waste disposal charges. A recent target set by the European Union is to recover 70% of construction and demolition waste by weight by 2020 (European Commission, 2008). The Brazilian scenario is, however, very different. Firstly, government supervision is poor in spite of recent progresses in regulations, secondly, investment in waste recycling plants is very limited (Miranda et al., 2009). Moreover, there is a lack of construction waste quantitative information, a

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key parameter for the development of policies aimed at waste reduction practices (Ângulo, 2005).

The reduction of waste generation is a complex process, since it may require construction companies to adopt a new mindset and change approaches. The understanding of how and where waste is generated and the adoption of benchmarks can greatly contribute to disseminate this new culture (Formoso et al., 2002). The planning undertaken by construction companies to achieve optimal waste management is an important strategy in improving production processes and reducing waste generation (Saez et al., 2012).

The quantification of waste generation can contribute to controlling waste and provide a benchmark for reduction. However, it can be a difficult task because of the specific characteristics and the wide range of materials, construction system and design features used in different construction projects. The occurrence of waste for most materials is usually the result of a combination of factors, rather than the product of a single isolated incident (Formoso et al., 2002). Unsuitable construction methods, poorly trained workers and not enough attention given to design supervision and management are frequently listed as the major culprits behind the generation of waste in construction (Scheer et al., 2007).

This study investigates how the generation of waste in the construction of new high-rise residential buildings is affected by the design characteristics and the production system, since both are the two major sources of construction waste mentioned in the literature.

The core research questions of the investigation consist of "*what are design and production main variable? how they influence the waste generation during the production of high-rise residential buildings?*" The main objective of this study is to propose a model to estimate the generation of construction waste during the production process of high-rise residential buildings through design and production features.

1.1. Construction waste issues

According to Osmani (2011), construction waste issues have been investigated by several authors, manly with a focus on the sources, characterization and recycling. Most efforts have been directed towards the wasted produced, while limited resources are dedicated to studies aiming at eliminating waste generation (i.e., reducing waste at source).

Although waste is actually produced when construction activities start, it is a result of the decisions taken in preproduction stages. Thus, the design phase is a key step affecting the generation of construction waste (Mália, 2013; Osmani, 2011). In this context, several authors underscore the influence of design phase decisions on the generation of waste during the production phase (Souza and Deana, 2007; Osmani et al., 2008; Boehm, 2012; Keys and Baldwin, 2000). Osmani et al. (2008) and Formoso et al. (2002) suggest that a considerable share of the waste produced can be predicted and eliminated, and poor management of the phases prior to production account for the most important causes of excessive waste production. Poon (2007) points that all parties involved in the building process should be also considered.

The present study investigates design and waste generation from the architectural shape of the building, expressed in terms of compactness of the building design. This design feature has been associated with the cost and consumption of materials expressed by a 'compactness index'. Mascaró (2010) proposes an economic index of compactness (EIC), which is an attempt to associate direct costs (materials, equipment and labor) with the compactness (shape) of the building. Larger external perimeters are associated with larger façades and the need for more coatings and coverings, which increases the potential for waste generation as more labor, transportation and materials are required (Souza and Deana, 2007). Thus, the compactness of the design should be investigated vis-à-vis waste generation and checked for with greater or lesser material consumption.

The study also investigates production aspects related to waste generation. Poon (2007) argues that recent studies have shown that about 10% of construction waste is generated from the cutting of building materials during the construction process.

In this context, Baldwin et al. (2009) state that prefabricating building elements off-site in precast designs can effectively reduce the generation of construction waste on site. Design standardization is a pre-requisite criterion for precast operations and it is most suitable for the design of high-rise residential buildings. From the comparison of the waste generated in rise buildings with three different construction methods, Lachimpad et al. (2012) suggest that Industrialized Building System is most efficient with a waste generation rate of 0.016 tons/m^2 floor, while Mixed System presents 0.030 tons/m^2 and the Conventional Construction 0.048 tons/m^2.

The study conducted by Wang et al. (2014) shows six critical production factors that influence waste generation: large-panel metal formworks; prefabricated components; fewer design modifications; modular design, investment on waste reduction and economic incentive.

However, according to Osmani (2013), designing out waste has not been the main objective of architects and contractors in the context of sustainable construction. Waste generation is still being affected by a wide practice of not embedding waste reduction in briefing and contractual documents. The author also reports the lack of designers' understanding of design waste origins, causes and sources.

1.2. Construction waste quantification methods

Different methods and waste quantifying parameters are presented by several academic studies all over the world, i.e. Pinto, 1999 (Brazil); Katz and Baum, 2010 (Israel); Llatas, 2011 (Europe); Bania et al., 2011 (Greece), Saez et al., 2012 (Spain).

In Brazil the research conducted by Pinto (1999) is of great importance and triggered a series of subsequent studies to estimate construction waste generated in different Brazilian cities. The method is based on three indicators: construction waste from new building; waste from renovations, extensions and demolitions; and, waste from informal and irregular construction. The waste generation rate proposed by this author is 150 kg/m^2.

Katz and Baum (2010) propose a model to predict the flow of waste in construction, from the beginning to the end of the production phase of new buildings. Stages of construction are classified as structural elements, structural elements and finishes early (concurrent) and final finishes. The total amount of waste generated during the construction of residential buildings was estimated at 0.2 m^3/m^2 by those authors.

In Spain, Saez et al. (2012) have employed the method developed by Katz and Baum (2010) to quantify the RCD generated in the construction of new residential buildings. Three measurements are determined: the total volume of waste generated in construction; each type of waste generated locally; and, the waste volume (m^3) in relation with the building total area (m^2).

Bania et al. (2011) present a web-based Decision Support System for the optimal management of construction and demolition waste, based on the typical construction practices in Greece. This tool estimates the generated quantities of 21 different waste stream produced by two main processes (renovation and demolition) for four building types: residential, office, commercial and industrial. With the use of mathematical programming, the tool