



# Developing a quantitative construction waste estimation model for building construction projects



Yashuai Li<sup>a</sup>, Xueqing Zhang<sup>b</sup>, Guoyu Ding<sup>c,\*</sup>, Zhouquan Feng<sup>b</sup>

<sup>a</sup> School of Economics and Management, Beihang University, Haidian District, Beijing 100191, China

<sup>b</sup> Department of Civil and Environmental Engineering, The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China

<sup>c</sup> School of Environment, Tsinghua University, Haidian District, Beijing 100084, China

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## ABSTRACT

Construction and demolition waste is a major source of urban solid waste, frequently accounting for 10–30% of the total waste disposed of at landfills in many cities around the world. There is a recognized need to manage the construction waste in order to maintain a sustainable environment. The successful implementation of construction waste management depends on a number of factors. One critical factor is the need to accurately estimate waste generated from construction projects. In this regard, this paper proposes a quantitative construction waste estimation model for building construction projects, which can enhance the accuracy in the estimation of construction waste at the project level. In the development of this model, a theoretical analysis of the construction process and the construction waste generation process has been conducted. Specifically, this model integrates the mass balance principle, work breakdown structure, material quantity takeoff, conversion ratios between different waste measurement units, and the wastage levels of various materials used in different work packages. The proposed model is able to predict the quantities of various kinds of construction waste from a building project, to track the origin of construction waste (i.e., from which work package a particular kind of waste is generated and how much) and to help contractors investigate the potential improvements for waste management. An illustrative example is provided to demonstrate the application of this quantitative construction waste estimation model.

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## 1. Introduction

Construction and demolition waste (referred to construction waste in this paper) is a major source of urban waste and usually accounts for 10–30% of the total waste landfilled (Agamuthu, 2008). The substantial amount of construction waste has been placing a heavy burden on the sustainable development of many large cities in both developed and developing countries/regions. In Japan, 20% of the total waste was generated from the construction industry in financial year 2007 (Japanese Ministry of Environment, 2010). In Hong Kong, 5% of total construction waste usually constitutes around 25% of the total waste landfilled and 95% is disposed of at public filling areas (Hong Kong Environmental Protection Department, 2015). Therefore, it is estimated that Hong Kong may run out of both public filling areas and landfill spaces within this decade at the current waste generation rate (Jaillon et al., 2009). In the European Union, construction waste consists of more than 30%

of the total solid waste (Eurostat, 2015). In Mainland China, construction waste generation is estimated to be over 1.5 billion tons in 2014 and comprises around 40% of the total waste (CSACWUTI, 2015).

In a context of increasing international concern about sustainability, various policy instruments have been established to reduce construction waste and to improve the recycling rate of construction waste, i.e., site waste management plan (Tam, 2008) and landfill charge scheme (Hao et al., 2008). The effective application of these policy instruments depends heavily on the accurate quantification of construction waste at the project level, which is a practical level for both the government and the construction industry to take effective measures to control construction waste. From the perspective of the government, the authorities require an accurate estimation of construction waste in order to establish appropriate policies, guidelines, strategies and codes of practice for sustainable construction waste management in view of local situation, for instance, in the development of optimal waste treatment facilities, the right level of waste charge, and the appropriate incentives for construction companies to take proactive measures (e.g., site waste management plan and application of green building

\* Corresponding author.

E-mail address: [guoyuding@gmail.com](mailto:guoyuding@gmail.com) (G. Ding).

technologies) in minimizing construction waste. From the perspective of the construction industry, a construction waste estimation system at the project level allows individual companies to accurately estimate the quantities of various kinds of waste generated in each project and to take active waste prevention, reduction and utilization plan within a project or between the projects undertaken by a construction company or across the whole construction industry.

A number of quantitative methods have been proposed to estimate construction waste generation. Li and Zhang (2013) divided these methods into three categories: survey-based percentage method, generic project parameters based models and macroeconomic models. Wu et al. (2014) further reviewed waste estimation methods from the perspectives of waste generation activity, estimation level and quantification methodology and classified them into six types including site visit method, waste generation rate method, lifetime analysis method, classification accumulation method, variables modeling method and other particular methods. They also pointed out that construction industry needs to forecast the future waste generation accurately. In this paper, the waste estimation models could be organized according to Li and Zhang (2013).

- In the survey-based percentage method, the average waste percentage of the total amount of construction materials consumed in these projects can be determined by conducting a survey of some similar construction projects and is to estimate the total waste from a construction project (Bossink and Brouwers, 1996).
- In the generic project parameters based models, these parameters include construction areas, wastage levels, structure type and function, and construction stage. Fatta et al. (2003) assumed average generation of construction waste with respect to construction areas and thus estimated the total waste generation in Greece. Kofoworola and Gheewala (2009) utilized construction area to estimate the construction waste generation in Thailand. Villoria Sáez et al. (2012, 2014) employed construction area as one variable for estimating waste generation. Poon et al. (2004) observed several public housing projects and presented a list of waste levels for different kinds of materials. Solís-Guzmán et al. (2009) investigated the wastage levels for housing projects from 1 to 10 floors according to budget classification. Llatas (2011) proposed an estimation model based on wastage levels (waste factors) according to European waste list. Li et al. (2013) illustrated a novel model to determine the average wastage level of housing projects in China based on mass balance principle. Huang et al. (2011) estimated waste generation in Taiwan from the perspectives of structure type and function etc. Ding and Xiao (2014) considered building structure types and design in different decades to forecast waste generation in Shanghai, China. Katz and Baum (2011) conducted field observations for 10 construction sites and illustrated an accumulation waste estimation model with respect to construction stages. Bakshan et al. (2015) demonstrated a method to predict waste generation according to construction stages, wastage levels of major waste streams, etc.
- In the macroeconomic models, the variables could include the population size, construction permits and construction material production. Wang et al. (2004) utilized the number construction permits to estimate waste generation in Massachusetts, United States. Shi and Xu (2006) employed the annual cement production to forecast the total quantity of concrete waste. Cochran and Townsend (2010) adopted material flow analysis method and utilized construction material production to estimate the future waste generation.

This study aims to develop a quantitative construction waste estimation model for building construction projects. This model

will enhance the accuracy in the estimation of construction waste at the project level. It will be able to predict the quantities of various kinds of construction waste from a project and to track the origin of construction waste (i.e., from which work package a particular kind of waste is generated and how much). In this regard, contractors could develop their waste estimation templates based on this model by incorporating their experience and knowledge on wastage levels and controlling the accuracy of estimation through levels of detail of work breakdown structure. They could therefore find potential improvement measures for managing the most significant waste streams.

## 2. Overall methodology for model development

In the development of the construction waste estimation model, a theoretical analysis of the construction process and the construction waste generation process has been conducted. Particularly, work breakdown structure (WBS) is employed to represent different construction processes. In a WBS, the work packages in the lowest practical level are referred to as terminal work packages in this paper. Based on WBS, construction material quantity takeoff helps determine the quantities of required materials for a specific building project. The mass balance principle and material flow analysis are utilized to investigate the waste generation process for different kinds of materials. In addition, the conversion ratios are used to help contractors calculate the weight and volume of materials and waste for transportation. Wastage levels of materials in each terminal work package are used to measure the waste generated from different construction processes. In this regard, the proposed waste estimation model integrates work breakdown structure (WBS), material quantity takeoff, conversion ratios between different waste measurement units, and wastage levels of different materials used in different work packages. Fig. 1 illustrates the overall methodology and the details of the model are discussed in the following sections.

## 3. Proposed construction waste estimation model

### 3.1. Work breakdown structure (WBS)

#### 3.1.1. Concept of WBS

The WBS is a progressive hierarchical breakdown of a project into smaller and smaller work packages to the lowest practical level (referred to as terminal work packages in this paper), at which various construction engineering and management functions can be reasonably applied. As a construction information classification mechanism that decomposes project elements into a manageable level and an integrating mechanism that provides a common perspective to relevant construction business functions (Jung and Woo, 2004), the WBS is regarded as a powerful project structuring tool, which has been widely applied to sequence construction work activities, conduct material quantity takeoff, estimate construction duration and cost, integrate cost and schedule, measure the construction progress, enhance construction safety and quality, and improve the interface management (Chen, 2008; Chua and Godinot, 2006; Kim et al., 2008).

#### 3.1.2. WBS based on Uniformat II

One widely accepted standard classification is the Uniformat II elemental classification, where common elements of buildings are defined based on their functions regardless of their design specification, materials used, and/or construction method/technology applied (Charette and Marshall, 1999). A building construction project is classified into four levels in Uniformat II, namely, major

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