Resources, Conservation and Recycling 100 (2015) 70–80

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

A field based methodology for estimating waste generation rates at various stages of construction projects

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ARTICLE INFO

Article history:
Received 22 November 2014
Received in revised form 30 March 2015
Accepted 4 April 2015
Available online 16 May 2015

Keywords:
Construction waste
Generation rates
Waste management plan

ABSTRACT

The growth in construction activities over the past two decades has resulted in a parallel increase in the amount of generated construction waste. This growth, coupled with shortages in landfill space particularly in urban areas, has proven to be a challenging stressor to the environment. Management of construction waste has thus become a problem attracting increasing attention worldwide. In this context, the quantification of waste streams generated from various construction stages is the first step for managing construction waste. In this study, a methodology for quantifying waste streams arising at various construction stages is proposed. The methodology is then tested at a field scale to estimate generation rates for major waste streams and the total construction waste generation rate for the purpose of developing a generalized construction waste management plan that can be applied at a city/regional/country level. The results of the study reveal that the total construction waste generation rate falls within the range of 38–43 kg/m^2, with masonry and concrete constituting more than 60% of the total waste. The study concludes with a set of recommendations addressing the most important issues contributing to a successful implementation of an integrated construction waste management plan.

1. Introduction

Waste is defined as any material by-product of human or industrial activity that has no residual value (Ortiz et al., 2010). Construction and demolition waste (CDW), in particular, is a mixture of surplus materials generated during new construction, renovation, and demolition of buildings, roads, bridges, and other structures (Cheng and Ma, 2013). Construction waste (CW), the focus of this study, is a subset of CDW and includes waste generated during new construction. CW constitutes more than 10% of the waste generated worldwide (Begum et al., 2009), most of which remains improperly managed and disposed-off in undesignated areas particularly in developing countries (Llatas, 2011). As such, the construction industry has been increasingly under pressure to improve CW management due to associated adverse environmental impacts including depletion of natural resources, air pollution, surface and ground water pollution, risks to public health, and losing considerable land resources for waste landfilling (Dixit et al., 2010; Poon et al., 2003; WCED, 1987).

The need for environmental protection led to the development of guidelines and regulations to improve the management of CW with the goal of reducing the amount of waste sent to landfills and promoting recycling/re-use programs (Lennon, 2005; Zhao et al., 2010). For this purpose, the quantity and quality of CW are critical elements of a waste management plan. In this context, a building construction project passes through several construction stages (i.e. shoring, excavation, foundation, structural concrete, masonry, and finishing), generating different types of waste materials that can be classified under three major categories: (1) inert (i.e. soft such as soil and sand and hard such as rocks, concrete, aggregates, plaster, bricks, masonry blocks, glass, and tiles), (2) non-inert (i.e. drywall/gypsum, metals, wood, paper, cardboard, packaging, plastic), and (3) hazardous (i.e. flammable materials such as paint, corrosive materials such as acids and bases, explosive materials that undergo violent chemical reaction when exposed to air or water) (Begum et al., 2006; Bergsdal et al., 2007; Cochran et al., 2007; Jalali, 2007; Li, 2002; Li et al., 2013; Lu et al., 2011; Malia et al., 2013; WRAP, 2010). Inert materials, also known as public fill, are suitable for land reclamation and site formation and can be used to produce recycled construction materials. Non-inert materials are chemically active substances that are not harmful to human health and the environment (i.e. non-hazardous), whereas hazardous materials are dangerous or potentially harmful either

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http://dx.doi.org/10.1016/j.resconrec.2015.04.002
0921-3449/

Table 1
Methods to estimate quantities of CDW.

Method criterion	Reference	Explanation	Limitations
Visual observation	Brown et al. (2006)	• Requires the presence of a professional estimator • The major material types and the sub-categories of each type are visually estimated • No sorting is required • The dimensions of the load of waste are measured • The volume of all categories and sub-categories are calculated and converted to weights using typical waste density	• Depends on the experience of the visual estimator • Provides approximate data • Not sufficient for developing detailed waste planning strategies
Constructed area	Poon et al. (2001)	• CW (in m^3 or kg) = $GFA \times WI$ • GFA is the Gross Floor Area (in m^2) • Waste Index (WI) is the amount of CW per m^2 of Gross Floor Area (GFA)	• Provides information on bulk waste generated without categorizing it by type
	Jalali (2007)	• Provides a "Global Index" based on a database that is building type specific • Waste generated is categorized by material type • Useful for estimating waste on future projects	• Depends on availability of a regional database that requires continuous update • Might not be suitable for other regions
Building components	Jalali (2007)	• Provides a "Component Index" which is the minimum unit that can be considered as an independent part of the construction process (e.g. 1 m^2 of foundation) • Different types of waste streams are estimated for each construction component based on manual measurements taken by field workers	• Requires labor-intensive measurements and updates • Difficult to implement in practice since taking manual measurements might interfere with normal site activities (Cheng and Ma, 2013)
Materials flow analysis approach	Cochran and Townsend (2010)	• $CW = M \times w_c$ • M is the amount of construction materials purchased • w_c is the average portion (%) of each material discarded during construction. It can be estimated from construction guides (e.g. Delpico, 2004)	• Construction guides from which "w_c" can be estimated rely on industry surveys • The accuracy of the estimated data depends on the accuracy of these surveys
	Li et al. (2013)	• $CW = M$ x MWR • M is the amount of construction materials purchased • MWR is the waste rate (%) of each material discarded during construction, as estimated by the project manager	• Accuracy and reliability of waste generation rates rely on the accuracy of MWR provided by the project manager
Construction databases	Llatas (2011)	• Relies on quantities obtained from budget records • These records are obtained by studying more than 20 dwellings with similar typological characteristics	• Databases used may not be applicable in other regions with buildings of different typological characteristics • Cannot be used for high-rise buildings
Forms of physical layout	Lau et al. (2008)	• Four forms of CW layout (stockpiled, gathered, scattered, and stacked) are proposed • For example, in the case of stockpiled waste, the volume of waste is estimated using the equation of the "pyramid" volume"	• Provides rough data which is not enough for detailed waste planning strategies
Software accounting tools	BRE (2008)	• "SMARTWaste" software tool • Developed by the Resources Efficiency team at the UK Building Research Establishment (BRE) • This tool relies on data obtained from the UK construction industry	• Its application is limited to certain regions where the building construction industry has similar characteristics to the UK construction industry

by themselves or through interaction with other materials/factors. Both non-inert and hazardous materials cannot be used for land reclamation and should be disposed of at landfills (EHS, 2011; EPD, 2013). In developed economies where strict CW management policies are implemented, these wastes are segregated on site for reuse or recycling purposes (Malia et al., 2013). However, at other locations, these three types of waste are commingled and dumped haphazardly due to either the absence of regulations related to CW management, such as the case of Lebanon (Srour et al., 2013), or the non-implementation of these regulations, such as the case of Turkey (Esin and Cosgun, 2007).

The estimation of waste generation rates from various waste streams of construction activities is identified as a meaningful tool to promote construction waste management. It can be used to predict the amount of construction waste generated in a project, which will help project stakeholders to prepare proper practices for managing CW and assess the effectiveness of these practices by comparing the estimated waste rates across different projects (Lu et al., 2011; Wu et al., 2014). For this purpose, several methods have been reported in estimating the quantity and quality of CDW (Table 1).

Existing CDW estimation methods, presented in Table 1, have various limitations. While some methods provide approximate data that are invariably not sufficient to develop detailed waste planning strategies (Brown et al., 2006; Lau et al., 2008; Poon et al., 2001), others target a particular type of buildings (e.g. Llatas, 2011). A few additional methods depend on external sources of data such as regional databases, construction guides, industry surveys, or site personnel's perceptions (BRE, 2008; Cochran and Townsend, 2010; Jalali, 2007; Li et al., 2013), and thus, may not be applicable in other regions with different typological characteristics and construction techniques. Furthermore, most of these methods quantify CW in developed countries and are often not applicable in the context of less developed economies. This study targets these limitations by proposing a practical and accurate waste estimation methodology that categorizes CW by major material types and estimates the waste generation rate for each type as well as the total construction waste generation rate at a larger scale (i.e. economy of scale). As such, the proposed methodology allows for developing detailed waste planning strategies and is particularly useful in cases where CW related data is limited. It relies on simple linear equations based on data obtained from project records (e.g. structural