Waste quantification models for estimation of construction and demolition waste generation: a review

Ahmad Firman Masudi* and Che Rosmani Che Hassan
Faculty of Engineering, Department of Chemical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
E-mail: firman_masudi@yahoo.com
E-mail: rosmani@um.edu.my
*Corresponding author

Noor Zalina Mahmood and Siti Nazziera Mokhtar
Faculty of Science, Institute of Biological Sciences, University of Malaya, 50603 Kuala Lumpur, Malaysia
E-mail: alin@um.edu.my
E-mail: fazziera@yahoo.com

Nik Meriam Sulaiman
Faculty of Engineering, Department of Chemical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
E-mail: meriam@um.edu.my

Abstract: Quantification is crucial for construction and demolition waste management. Accurate estimation can be satisfied by developing waste quantification model that is applicable for regional or nation-wide C&D waste generation. This paper presents a review on quantification models for C&D waste from literatures and how they correlate. Most studies combine the empirical waste assessment data or waste generation factor obtained in the field with area of activity level extracted from national statistical database from their respective countries, which provides annual data on sector activities. National or regional estimates provide general figures and forecasts for annual C&D waste generation. Studies found that waste generation factor will differs according to locations. Since volume and characteristic of waste are crucial for waste quantification, quantitative data record from waste audit findings could benefit the authorities for the annual estimates. National C&D waste reduction plan should start from well-established waste minimisation plan at project sites.

Keywords: construction and demolition waste; C&D waste; C&D debris; waste estimation; waste quantification model.
1 Introduction

The first step towards construction and demolition (C&D) waste management is to determine its generated amount (Martinez-Lage, 2010). A recent bibliometric analysis showed that C&D waste generation, reduction, and recycling are three of the most important topics in C&D waste research (Lu and Yuan, 2011). Lu and Yuan (2011) agreed that the future challenge of this study is to establish standardised measurement...
Waste quantification models for estimation of construction and demolition technique for C&D waste generation to enhance effectiveness of waste management (WM) approaches and to compare WM performance across various countries. Estimation of national or regional C&D waste generation can be performed given that the information and data are available and accessible (Franklin Associates, 1998; Gheewala and Kofoworola, 2009). Accurate estimation can be satisfied by developing waste quantification model that is applicable for regional or nationwide C&D waste generation. Construction authorities could benefit the annual estimates for predicting the lifespan of existing yet depleted landfill areas, or assessing the feasibility of C&D waste recycle program (Yost and Halstead, 1996; Cochran et al., 2007; Gheewala and Kofoworola, 2009). Construction authorities as the policy maker and enforcer could develop and issue new regulations or incentives to stimulate and encourage the use of low-waste building technology, better WM practices, establishing formally standardised systems to record quantitative data, and introduce useful guidelines and measures to a more manageable and minimised construction waste generation (Jaillon et al., 2009). Enforcement is essential to ensure that the requirements and standards are fulfilled.

This paper reviews the available waste quantification models from previous studies, which have been utilised in certain countries, while providing recommendation for further studies in establishing more accurate and reliable waste quantification model. Quantification models available from literature had been introduced and implemented for quantifying regional and nationwide C&D waste generation. Models reviewed here focused on building-related C&D debris estimates from construction, demolition, and renovation projects which consist of residential and non-residential buildings. Waste generated from public works, and infrastructure projects were not considered due to lack of available data. The models are not universally applicable, as the amount of C&D debris generated in any region or nation depends on the general economic conditions of the vicinity, the weather, major disasters, special projects, and local regulations (Franklin Associates, 1998). Jaillon et al. (2009) agreed with the mentioned finding and concludes that the amount and type of C&D waste depend on: type of projects (i.e., residential or non-residential); size of the projects; and construction technology employed.

2 Methodology

Recent research trend in this field point out that survey and case study are the main methodologies for data collection (Yuan and Shen, 2011). Franklin Associates (1998) reported that conducting survey (sampling and weighing) at landfills, which is often used for determining local WM system needs, would be the preferred method for this study if sufficient time and funds were available. However, even on the local level there may be significant barriers to this method. Sampling from mixed waste streams with statistical confidence is very difficult, time consuming, and costly. Locating all the places where C&D debris is discarded is not a trivial matter in some localities, and obtaining permission to sample at private landfills can be a major challenge. For national study of this type, this method would be both cost and time prohibitive. Early efforts to estimate C&D waste have employed the same techniques used to estimate municipal solid waste, which is by using per capita multipliers (Yost and Halstead, 1996). It was found that per capita multipliers simply do not reflect C&D activity. Yost and Halstead (1996) proposed a more accurate method that combines building permits data from national statistics,
which provide the number and estimated financial value, with empirical waste generation rate data.

Waste characterisation is the initial stage of data gathering and it is very crucial (Gheewala and Kofoworola, 2009). The process consists of identifying type of waste materials being generated. Most authors conducted detailed study for characterisation of various types of C&D waste materials. Yost and Halstead (1996) performed case study on gypsum wallboard waste generation in the USA, while Hsiao et al. (2002) studied the national concrete waste output in Taiwan, but most studies (Franklin Associates, 1998; Fatta et al., 2003; Bergsdal et al., 2007; Cochran et al., 2007; Gheewala and Kofoworola, 2009; Martinez-Lage et al., 2010) focus on major type of C&D waste with significant amount, such as concrete, bricks, timber, steel and drywall.

Data gathered from C&D sites are described as ‘waste assessment data’. These data were utilised to produce the average waste generation rate per area, which is usually expressed in unit of amount (weight or volume) per area of activity. The waste generation rate per area is considered as ‘waste factor’ in the quantification model. Most studies combine the empirical waste assessment data (waste factor) obtained in the field with area of activity level extracted from national statistical database from their respective countries, which provides annual data on sector activities (number of construction or demolition permits, construction value, and area of activity level), in this case, the National Census Bureau in the USA, National Statistics Institute of Spain, Building Research Institute of Taiwan, and so forth. The outcome is the quantity of national C&D waste generation in particular year. The methodology should be well suited for periodic updating or forecasting (Franklin Associates, 1998). There are a number of waste quantification models available from literature for estimation of construction waste generation which have been implemented in various countries as summarised below.

2.1 Model suggested by Yost and Halstead (1996), Franklin Associates (1998), Cochran et al. (2007), and Bergsdal et al. (2007)

Yost and Halstead (1996) and Franklin Associates (1998) combine National Statistical data and waste assessment data from waste sampling on numerous random sites across the USA. The aforementioned authors could be considered as one of the pioneers who introduced this methodology. Yost and Halstead (1996) performed a case study on gypsum wallboard waste generation in the USA to assess the feasibility of wallboard recycling program, while Franklin Associates (1998) performed a more comprehensive study for national C&D waste generation rate. Total waste generation of the respective year (tons/year) is the product of total area (sq ft) multiplied by the average waste generation (lb/sq ft) attained from the empirical waste assessment data (waste sampling). The accuracy of the estimates depends on accuracy of data (Cochran et al., 2007). Table 1 shows the example calculation for new residential construction from studies conducted by Franklin Associates (1998). The quantification model, which is also presented by Cochran et al. (2007) and Bergsdal et al. (2007), may be described in a simple term as follows:

\[
\text{Waste produced in a region} = \left( \text{Activity level of construction; demolition; or renovation in a region} \right) \times \left[ \text{Waste produced per activity} \right]
\]
Franklin Associates (1998) reported that the average waste generation rate for residential construction, non-residential construction, residential demolition, non-residential demolition, and non-residential renovation are 4.38 lb/sq ft, 3.89 lb/sq ft, 115 lb/sq ft, 173 lb/sq ft, and 17.67 lb/sq ft respectively.

The average compositions of waste materials are also part of the waste assessment data obtained from site surveys. For example, Bergsdal et al. (2007) found that concrete/bricks and timber are the main waste materials for new construction projects in Norway with 67% and 15% respectively, while for demolition projects, 85% of waste generated is concrete, which is considered as the main waste generating activity. Bergsdal et al. (2007) also predicted that concrete/brick waste generation will increase by four-fold and timber waste will increase by double in 2018 by using Monte Carlo iterative tool by accounting building lifetime (60–90 years old). Meanwhile, Cochran et al. (2007) found that C&D debris composition generated was 56% concrete, 13% wood/timber, 11% drywall, and 7% asphalt roofing materials.

### Table 1 Residential construction debris worksheet

<table>
<thead>
<tr>
<th>Method to use</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Start with total dollars of new construction, from Census Bureau.</td>
</tr>
<tr>
<td>Current Constr Reports, C-30.</td>
</tr>
<tr>
<td>2 Calculate sq ft of new construction from total dollars and $/sq ft construction cost.</td>
</tr>
<tr>
<td>3 From empirical waste assessment, estimate lb/sq ft of new construction.</td>
</tr>
<tr>
<td>4 Calculate total generation</td>
</tr>
</tbody>
</table>

**Calculation**

1. C-30, Residential construction (1996) – $181,795,000,000
   - (Includes private new housing units and public housing and redevelopment)

2. 1995 Census data, Table 1175 of 1996 Stat Abs. (Note: whole industry not included)
   - Residential construction $127,900,000,000
   - Residential sq ft of new constr $2,172,000,000 sq ft
   - Cost of new construction $58.89 per sq ft
   - Total sq ft of new constr – 181,795,000,000 / 58.89 / 1.03 = 2,997,326,036 sq ft
     - (Includes 3% inflation factor)
   - Average generation – 4.38 lb/sq ft

3. Total new residential construction debris – 6,564,000 tons/year

**Source:** Franklin Associate (1998)

### 2.2 Model suggested by Gheewala and Kofoworola (2009)

Gheewala and Kofoworola (2009) also described their findings with similar approach for new residential and non-residential projects in Thailand. The model proposed does not consider demolition, renovation, and infrastructure projects due to lack of data. This quantification model was developed to assess the feasibility of national C&D waste recycling program. Recycling was being promoted as a method of managing waste as it can save energy consumption in construction industry, reduce environmental impacts,
and create employment. The authors found that the average waste generation rate for new residential and non-residential projects is 21.38 kg/m² and 18.99 kg/m², respectively. The quantification model may be described in the following term:

\[ Q = A \times G_{av} \times P_x \]  

(2)

\( Q \) = quantity in tons; \( A \) = area of activity in m²; \( G_{av} \) = waste generation rate; \( P_x \) = percentage of waste material.

2.3 Model suggested by Lu et al. (2011)

Lu et al. (2011) also quantified Waste Generation Rate (WGR) on a number of high-rise building projects in Shenzhen, South China using similar fashion with Gheewala and Koforowola (2009). In this exercise, waste generated from four different trades (concreting, formwork, masonry, and plastering) were analysed and sampled for a common area within a single floor as representative so that WGR derived could be applied to the whole floor. Six materials were sorted and weighed and quantified using the following term:

\[ WGR = \sum m_i / A \]  

(3)

WGR = waste generation rate; \( m_i \) = the quantity of one waste material for a single bucket; \( A \) = selected area for on-site sorting and weighing.

Lu et al. (2011) found that WGRs in Shenzhen are ranging from 3.275–8.791 kg/m² and timber and concrete are the largest components of waste generated.

2.4 Model suggested by Fatta et al. (2003)

Fatta et al. (2003), on the other hand, developed the model with different approach. ‘waste density’ term was introduced and waste generation rate employing ‘volume per area’ factor instead of ‘weight per area’ like previous discussed models. The author also made use of some representative assumptions for the waste generation rate and density of waste that represent the characteristics of national waste generation based on average value from the National Statistical Services of Greece. Hence, the applied models for C&D activities respectively are as follows:

\[ CW = (NC + EX) \times VD \times D \]  

(4)

\( CW \) = construction waste in tons; \( NC \) = new construction in m² (from NSSG); \( EX \) = extension infrastructure in m (from NSSG); \( VD \) = volume of generated waste per 100 m² = 6 m³ / 1000 m² (national average); \( D \) = density of waste = 1.6 ton/m³ (national average).

\[ DW = ND \times NF \times SD \times WD \times D \]  

(5)

\( DW \) = demolition waste in tons; \( ND \) = No. of demolitions (from NSSG); \( NF \) = mean value of no. of floors that building has = 1.3; \( SD \) = surface of each building being demolished = 130 m² (national average); \( WD \) = generation rate of each demolition = 0.8 m³/m² (national average); \( D \) = density of waste = 1.6 ton/m³ (national average).
2.5 Model suggested by Martinez-Lage et al. (2010)

Martinez-Lage et al. (2010) presented a procedure to ascertain the production and composition of C&D waste in any region. The aforementioned utilises data on the surface areas of newly constructed buildings and public works, renovations, demolitions which are estimated form available data for recent years, as well as information on the quantity of debris generated per surface area in any type of construction site, which is obtained from recently executed construction or from the ground plans of older buildings. The model proposed has been applied to Galicia, an autonomous community in northwest of Spain. There are several assumptions used to quantify building-related C&D debris, which are described below:

- the number of construction, renovation, and demolition works may be adjusted to a theoretical function (linear, parabolic, exponential, etc.) that varies over time (if data from a time series is known)
- construction activities distribution in the whole region is assumed to be the same every year
- surface area of construction, renovation, or demolition project can also be adjusted for a variable function over time
- quantity of waste generated per area is assumed to be the same for each type of construction.

The model can be described in the following term:

\[
R_{\text{build}} = \sum_{\text{counties}} \left( R_C + R_R + R_D \right) = \sum_{\text{counties}} \left( C_C \cdot S_C + C_R \cdot S_R + C_D \cdot S_D \right) \tag{6}
\]

\( R_{\text{build}} \) = C&D debris generated during a given year or horizon year (HY) distributed over counties; \( R_C \) = waste from new construction; \( R_R \) = waste from renovation; \( R_D \) = waste from demolition; \( S_C \) = total surface area for new construction; \( S_R \) = surface area for renovation; \( S_D \) = surface area for demolition; \( C_C \) = waste quantity per surface area of new construction; \( C_R \) = waste per area for renovation; \( C_D \) = waste per area for demolition.

Building permits data for each county were taken from the Galician Statistics Institute, National Statistics Institute of Spain, and Spanish Ministry of Public Works. Minimum data needed includes the number of buildings construction in the whole area over sufficient number of year to be able to establish correlation between year and number of building constructed, and an indicator on which to base the calculation of the mean area of existing construction. The procedure involves the computation of: Estimate number of buildings and surface area for all activities (construction, renovation, and demolition); Distribution of activities in all counties; Mean surface area of activities; Quantity per area of activities and; Total waste generated. Computing \( C_C \) involves calculating volume per surface area of new projects, which when multiplied by the density of debris will yield the weight of construction waste per unit of surface area. Computing \( C_D \) produces weight per area of old buildings (constructed in 1940s or 1950s), while for computation of \( C_R \), partial demolition is assumed to have the same composition as demolition debris and the rest of the type have the same composition as construction debris.

From the study conducted in Galicia, it was found that new construction work is estimated to generate 80 kg of waste per m², which is equivalent to 0.11 m³ of waste per
m² (density = 700 kg/m³). Demolition work is estimated to generate 1,350 kg of waste per m², while renovation work produces around 90 kg/m².

2.6 Model suggested by Llatas (2011)

This quantification model serves as a continuation from the model proposed by Martínez-Lage et al. (2010) to support the recent EU directive to become a ‘recycling society’ as the new challenge is to recover 70% by weight of C&D waste by 2010. Llatas (2011) utilises very systematical approaches by: identifying building elements of the project and their construction processes; employing waste classification system (including remains, soil, and packaging); and modelling (Figure 1). The analytical expressions used are the following:

\[
CW_B = \sum_j CW_{SBEj} = \sum_{ji} CW_{BEi} = \sum_{ji} CW_{Pi} + \sum_{ji} CW_{Si}
\]  

(7)

\[
CW_{Bj} = \text{volume of waste expected in the system building element ‘j’};
\]

\[
CW_{BEi} = \text{volume of expected waste from building element ‘i’};
\]

\[
CW_{Pi} = \text{volume of expected packaging waste element ‘i’};
\]

\[
\sum CW_{Ri} = \text{volume of remains expected from building element ‘i’};
\]

\[
CW_{Si} = \text{volume of expected soil in building element ‘i’}.
\]

\[
(CW_{B})_k = \text{code of packaging};
\]

\[
(EWL)_{Rk} = \text{code of remains} (EWL)_{Sk} = \text{code of soil};
\]

\[
Q_j = \text{amount of building element ‘j’};
\]

\[
F_P = \text{packaging waste factor};
\]

\[
F_C = \text{conversion factor};
\]

\[
F_R = \text{remains factor};
\]

\[
F_S = \text{soil factor};
\]

\[
F_I = \text{increased volume factor}.
\]

Based on case study for a number of dwelling projects in Spain involving over 200 building elements in a single project, waste generation rate (without soil) of 0.1388 m³/m² was obtained. A rate of packaging waste generation of 0.0819 m³/m² and a rate of 0.0568 m³/m², and soil generation of 0.2805 m³/m² were obtained. With this model, chances for construction waste recovery and prevention could be increased.

2.7 Model suggested by Hsiao et al. (2002)

Hsiao et al. (2002) has developed dynamic model for Taiwan’s domestic material flows of concrete waste and employ statistical analysis to obtain its future projections in order to increase awareness resources recovery by establishing up concrete recycle target and economic benefits assessment of concrete recycling. This model will quantify national concrete waste output as the major component of C&D waste from national C&D activities. This model did not consider concrete waste from civil and infrastructure works.
The total floor areas of activity based on C&D permits in Taiwan are acquired from the national statistical bureau. Due to the paucity of data on C&D waste in Taiwan, Hsiao et al. (2002) built the model to estimates relevant values. The concrete waste estimates are obtained from the Architecture and Building Research Institute (ABRI), under Taiwan Ministry of Interior. According to ABRI, it was found that the composition of concrete in construction waste in Taiwan is 21.17%. The model can be described in the following terms:

\[
W_C = d_{cc} \times \left[ \sum A_{ij} \times F_{ci} \right] \times P_{cc} \tag{11}
\]

\[
W_D = d_{cd} \times \left[ \sum A_{ij} \times F_{ci} \right] \tag{12}
\]

\( W_{C/D} \) = generation of waste concrete from construction/demolition (tonnes);
\( d_{cc/d} \) = specific gravity of C&D waste concrete (1.8 tonnes/m\(^3\) for construction, 2.2 tonnes/m\(^3\) for demolition);
\( A_{ij} \) = total floor area on use permits built (m\(^2\));
\( F_{ci} \) = volume of waste per area (m\(^3\)/m\(^2\));
\( P_{cc} \) = percentage of waste concrete in construction waste (21.17%).

Based on the annual data for total floor area of activity, Hsiao et al. (2002) employed an iterative model to predict future trends using MINITAB tool. Given the data for projected C&D waste generation, another dynamic model was employed to set a reasonable concrete recycle target (in percentage of total concrete output). Finally, economic benefits assessment was conducted to examine the feasibility of concrete waste resources recovery for each region.

2.8 Model suggested by Zhao et al. (2010)

Zhao et al. (2010) use similar approach in quantifying C&D waste generation for assessing the feasibility of C&D waste recycling in Chongqing, China. Currently, there are potential demand for secondary construction material in China such as aggregates, brick, wood, and metals. Waste quantification is a portion of this feasibility study and it is considered very crucial. The methodology is alike with previous studies whereby composition and waste generation rate were collected from a large number of C&D projects within Chongqing area. While data on activity rates and potential demand for secondary construction materials are gathered from Chongqing Statistical Yearbook and various literatures and references. Waste generation rate were described using the following terms:

\[
W_C = F_b \times D_c \tag{13}
\]

\[
W_d = F_b \times D_d \tag{14}
\]

\( F_b \) = floor area from municipal statistics; \( D_c \) = generation rate of construction waste; \( F_d \) = floor area of demolition; \( D_d \) = generation rate of demolition waste.

Result obtained from waste generation rate were inserted as parameter for calculating cost estimation, and investment analysis to help decision and policy-making processes in establishing C&D waste recycling program.
2.9 Model suggested by Wang et al. (2004)

Wang et al. (2004) had also developed spreadsheet-based system analysis model for estimating and economic assessment system based on mass balance principles, designed to track C&D waste stream through various stages of WM system. The model will quantifies the amount of several C&D debris materials (wood, asphalt shingles, carpet, and gypsum drywall) generated from construction, renovation, and demolition activities of residential buildings in Massachusetts, USA. These items have been selected by the state as items of high priority and it is believe that they constitute the largest share of C&D debris generated in residential projects as most of ABC (asphalt, bricks, and concrete) wastes are already recycled and the state intends to focus on materials that are not being recycled extensively. The developed methodology and tool are intended to assist the analysis and evaluation of C&D waste management policies and decisions making.

Data for the number of building permits and activity level are acquired from the Massachusetts building statistics. Wang et al. (2004) have utilised data from R.S. Means to estimate the quantity of wood, drywall, asphalt shingles, and carpet in various building projects, as shown in Table 2. R.S. Means is a company that specialises in publishing construction cost and productivity data. The next approach is to develop a spreadsheet-based system analysis model to assist the cost-benefit evaluation for various C&D waste management scenarios. The model was developed in Excel, and simulated using visual basic user interface as a tool with user interface for calculating the revenue versus cost for four restricted materials. The model schematics consist of generation estimator module, source separation module, and processing/recycling module (Figure 1).

By entering the appropriate housing statistics, the system calculates quantities (in square feet) of each of the specified material. Using appropriate unit weights for each of material, and the number and types of projects reported in building permit data, total tonnage of C&D debris for these waste materials in Massachusetts can be obtained. Wang et al. (2004) incorporated the result with geographical information system (GIS) that portrays spatial distribution of C&D debris for each region or towns in Massachusetts. This model can benefits regulators in identifying obstacles in recycling, and promote certain WM practices. This approach can lead to improvement on WM with cost-effective practice as successful and sustainable waste management plan (WMP) relies on justifiable financial framework for various participants (Wang et al., 2004).

Table 2

<table>
<thead>
<tr>
<th>Material</th>
<th>1-Story residence (1,600 ft²)</th>
<th>2-Story residence (2,000 ft²)</th>
<th>3-Story office (20,000 ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood (fbm/ft²)</td>
<td>3.21</td>
<td>3.18</td>
<td>0.634</td>
</tr>
<tr>
<td>Plywood (ft²/ft²)</td>
<td>3.27</td>
<td>3.01</td>
<td>N/A</td>
</tr>
<tr>
<td>Drywall (ft²/ft²)</td>
<td>3.29</td>
<td>5.57</td>
<td>1.52</td>
</tr>
<tr>
<td>Shingles (ft²/ft²)</td>
<td>2.49</td>
<td>1.25</td>
<td>N/A</td>
</tr>
<tr>
<td>Carpet (ft²/ft²)</td>
<td>0.8</td>
<td>0.8</td>
<td>0.6</td>
</tr>
</tbody>
</table>

Notes: * Calculated based on R.S. Means Residential Cost Data (1999a,b). The quantity of each material is calculated as per sq. ft. of gross enclosed area of the building.

3 Discussion

Quantification model suggested by Franklin Associates (1998) is considered to be the benchmark for an accurate and comprehensive national C&D waste estimation (for new construction, renovation, and demolition activities) due to strong empirical waste data obtained from rigorous waste sampling across the country. Cochran et al. (2007) and Bergsdal et al. (2007) employed a similar to Franklin Associates’ for specific region and with additional iterative forecasting method. Model suggested by Gheewala and Kofoworola (2009) and Lu et al. (2011) seems to be the least reliable due to over-simplification, and lack of strong database as they did not take account demolition and renovation activities. Model proposed by Fatta et al. (2003) provides a decent estimation but with over-simplified assumptions for national average waste generation rate, instead of breaking them down into certain categories (i.e., residential and non-residential), it did not take account waste from renovation activities. Recent quantification model employed by Martinez-Lage et al. (2010) can be regarded as the most accurate and comprehensive yet. The model uses reasonable assumptions, taking account C&D waste from all activities, density of waste, detailed waste assessment data from all counties of the region, and supported by strong data for building permits from a number of governmental sources. While quantification models proposed by Llatas (2011) provide a reliable and detailed approach for estimating waste generated from an individual construction project, taking account of soil, remaining (wrecked) materials, packaging, and even hazardous waste to comply with stringent EU requirements. Studies conducted by Yost and Halstead (1996), Hsiao et al. (2002), Zhao et al. (2010), and Wang et al. (2004) are more suitably preferred for assessing benefits and feasibility of recycle program for certain waste materials instead of providing general estimation for C&D waste database. These proposed models would be beneficial if integrated with cost-benefit and investment analysis, especially in assessing feasibility of recycling facility. Yuan and Shen (2011) point out that developing more state-of-the-art modelling and simulation techniques are the trend for future studies as C&D WM will continue to be a hot research topic. For example, recent study by Katz and Baum (2011) reported a
novel approach in waste modelling and found that waste accumulates in an exponential manner, i.e., significant amount is produced towards the end of a project.

4 Conclusions and recommendation

National or regional estimates provide general figures and forecasts for annual C&D waste generation. Studies found that waste generation factor will differs according to locations. Findings from these studies show that although the activity level of new construction projects are higher than demolition or renovation projects, the total amount of C&D debris from demolition projects are significantly higher (with large portion of concrete waste) than new construction or renovation projects. Since volume and characteristic of waste are crucial for waste quantification, there is a need for contractors that are obliged to account and record quantitative data from waste audit findings. Further studies include: developing and refining better predictive methodologies in obtaining waste generation rate; impose standardised waste characterisation; and establish an improved and more complete database that take consideration of other type of projects, such as civil/infrastructure projects.

Construction authorities should formulate standardised systems for waste auditing, and record-keeping for simplified environmental performance evaluation. Implementation of these measures must be supported by enforcement of regulations, including requirement for contractors to set up WMP in order to establish awareness of waste minimisation. Construction authorities should also have access to contractors’ empirical waste assessment data to enable reliable data gathering for the establishment of dependable database of information (for local, regional, and national level). Construction authorities could benefits the annual estimates for predicting the lifespan of existing yet depleted landfill areas, or assessing the feasibility of C&D waste recycle program. National C&D waste reduction plan should start from well-implemented and established waste minimisation plan at project sites and all construction personnel should be held responsible for its realisation.

Acknowledgements

The study was carried out as part of Universiti Malaya Research Grant for ‘Development of Construction Waste Index’ project (RG011/09SUS).

References


