Construction Waste Quantification and Benchmarking:
A Study in Klang Valley, Malaysia

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Abstract: Construction industry is a major contributor of negative impact to the environment. Estimation of construction waste amount is crucial for implementing waste minimization program. Estimation of construction waste amount generated is a mean in assessing the potential for waste reduction. Decision-making should be based on quantified measurements expressed in numerical terms to effectively minimize waste produced. A better understanding of C&D waste generation in terms of causes and sources can be achieved. Lack of benchmarking will hinder the implementation of more sustainable practices in the industry. The aim of this paper is to establish benchmarks on construction waste generation rate in Klang Valley (greater Kuala Lumpur), Malaysia using appropriate waste quantification method. Nine projects in Klang Valley constructed between 2006-2010 have been selected for this study, which include residential and commercial building projects conducted by a wide range of contractors employing conventional and IBS systems. Wastage level and waste index approaches had been employed in this study as tools for quantifying waste and also for environmental assessment. Types of waste that generated at significant amount, such as concrete, timber, reinforcement bars, tiles, screeds, and plaster are considered. Other factors, such as waste management provision, Environmental Management System (EMS) employed, record-keeping, contractors’ profile and other related policies are also assessed by conducting interviews with construction personnel. Based on the findings, overall site-management, size of project, and awareness of waste management among construction personnel are the most significant factors that contribute to construction waste generation. Currently, there is still relatively lack of waste minimization awareness among construction players in Malaysia as reflected by poor waste record-keeping, lack of waste sorting and recycling practice, low usage of IBS systems, and lack of supports from top management, clients, and authorities. The roles of construction authorities are essential in achieving the desired benchmark in waste generation rate for Malaysian context. Construction authorities as the policy maker and enforcer could develop and issue new regulations or incentives to stimulate and encourage waste management practices and the use of green building technology, establishing formally standardized systems in record-keeping of quantitative data, introduce useful guidelines and measures, conduct education and training to achieve sustainability and better environmental awareness among Malaysian construction players.

Key words: Construction waste, construction debris, waste index, wastage level, waste quantification, waste generation rate, benchmarking, Malaysia.

1. Introduction

Construction industry is a major contributor of negative impact to the environment. Construction materials production accounts for a significant percentage of energy consumed, and it is vital that the industry strives to reduce waste at all stages of construction [1]. The first step in implementing waste minimization program is to categorize and estimate the quantity and composition of construction waste generated. Waste quantification is important for a sound and adequate management in building construction [2]. It is stated that waste management decisions were often based on cursory observations, guesses, and simplified inferences by site managers [2].
people has had the most rapid development in recent years, and this is where most of construction activities take place.

There are many factors that contribute to construction waste amount. The amount of C&D debris generated in any region or country is influenced by: the general economic conditions of the vicinity; the weather; major disasters; and local regulations [9]. It is also concluded that the amount and type of C&D waste depends on: type of projects (i.e. residential or commercial); size of the projects (i.e. low-rise or high-rise); activity performed (i.e. construction, demolition, refurbishment); and construction technology employed (i.e. conventional or prefabrication) [17]. Poor material storage and handling practices were pointed out as the major sources of construction waste generation [18]. Construction waste sources were categorized and classified into six groups which include design, material procurement, material handling, operations, and residual [19]. For new building construction, there are two main types of waste, structure waste and finishing waste [18]. Concrete fragment, reinforcement bars, abandoned timber plate and pieces are generated as structure waste during the course of construction. Finishing waste (including a wide range of materials) is generated during finishing stage or wet trades, such as plastering, screeding, and tiling. For instance, surplus cement mortar scatters arising from screeding. Damaged materials like mosaic, tiles, ceramics, paints, and plastering materials are waste because mishandling. The packagings of public and household facilities are also part of finishing waste.

It is reported that, based on phase of building construction, timber formwork during super-structure phase was the major contributor of waste, contributing 30% of all waste identified [5]. Wet trades during finishing work such as screeding, plastering, and tiling were identified as the second major waste generator, at 20%. Moreover, findings suggested that design changes and leftover scrap are two of the most frequent causes of construction waste generation [20-22]. From the literatures, it can be concluded that reducing waste at the source is the most effective measure in waste management. Waste quantification can help to evaluate the effectiveness of the measures.

2. Methodology

Nine projects in Klang Valley constructed between 2006-2010 had been selected for this study, which mainly include residential and commercial building projects conducted by a wide range of contractors employing conventional and IBS systems. Conventional timber (and also plywood) formwork has been the backbone of construction method in Malaysia for many years, but IBS systems have starting to gain some acceptance and encouragement from government, although it is only limited to a small number of larger contractors. The majority of IBS systems employed are metal formwork system (steel or aluminum), and precast concrete system (for columns, beams, slabs, and wall) that relatively produce less waste. Most of the main contractors are G7 Grade under Malaysian CIDB (Construction Industry Development Board) grading system. Wastage level and waste index approaches had been employed in this study as tools for quantifying waste and also for environmental assessment. Wastage level and construction waste index concepts was first introduced by Poon in 2001 to establish benchmark data in Hong Kong’s construction industry [4]. Types of waste that generated at significant amount, such as concrete, timber, reinforcement bars, finishing waste from tiling, screeding, and plastering are considered. Other factors, such as waste management provision, Environmental Management System (EMS) employed, record-keeping, contractors’ profile and other related matters are also assessed by conducting interviews with construction personnel.

Major data extracted in this study are: Gross Floor Area (GFA), material order quantities, material workdone quantities, and construction debris disposal trip record. The main objective is to compare the total
Usually waste is estimated around 5-10% of materials ordered, while true amount and type of waste remains unknown and adequate management of waste is hindered [3-5]. Quantification provides a necessary tool for evaluating the true size of the waste and hence making the adequate decision for their minimization and sustainable management [2].

Waste quantification is all about good practice of site accounting and record-keeping and waste characterization is crucial to identify the composition of construction waste. It is a mean to estimate the quantity of construction waste generated, and thus, assessing the potential for waste reduction. This vital information can be obtained by construction waste assessment or audit. Thus, a better understanding of construction waste generation in terms of causes or source, amount, and compositions are achieved [1, 2]. Lack of benchmarking will hamper the implementation of more sustainable practices in the industry.

Waste quantification can also help in decision making in assessing the feasibility of recycling programs as practiced in countries like the US, Hong Kong, and Taiwan. Nonetheless, Malaysia is still lagging behind in establishing the quantified benchmark for construction waste generation rate among its contractors as compared to other countries (Table 1). Yet, there are still limited numbers of studies conducted and literatures available about construction waste quantification, especially in building construction projects. Publications related to construction waste for Malaysian perspective are mainly concerning qualitative approaches such as contractors’ attitude, behavior, and current status of waste management practices applied [6, 7]. Therefore, the aim of this study is to establish benchmarks on construction waste generation rate in Klang Valley, Malaysia using appropriate waste quantification method. Klang Valley is Malaysia’s most populated urban area which is mainly Kuala Lumpur Metropolitan area. This urban area of 7.2 million

### Table 1 Construction & demolition waste generation rate benchmarks in some countries.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Location</th>
<th>Scope of Activity</th>
<th>Waste Characterized</th>
<th>Waste Generation Rate</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>[8]</td>
<td>New Hampshire, U.S.</td>
<td>Construction, Renovation</td>
<td>Drywall waste</td>
<td>4.9 kg/m² (new residential), 2.44 kg/m² (new commercial)</td>
<td>To help decision-making in drywall recycling program</td>
</tr>
<tr>
<td>[20]</td>
<td>U.S.</td>
<td>Construction, Demolition, Renovation</td>
<td>Typical C&amp;D waste</td>
<td>4.38 lb/sq ft (new residential); 3.89 lb/sq ft (new commercial)</td>
<td>Benchmarking</td>
</tr>
<tr>
<td>[4]</td>
<td>Hong Kong</td>
<td>Construction</td>
<td>Typical C&amp;D waste</td>
<td>0.175 m³/m² (Public residential); 0.250 m³/m² (Private residential); 0.200 m³/m² (Commercial)</td>
<td>Benchmarking and decision making in recycling program &amp; IBS implementation</td>
</tr>
<tr>
<td>[10]</td>
<td>Taiwan</td>
<td>Construction, Demolition</td>
<td>Concrete waste</td>
<td>21% of waste; 2.4 MMT/year</td>
<td>Decision-making in concrete recycling program</td>
</tr>
<tr>
<td>[11]</td>
<td>Greece</td>
<td>Construction, Demolition</td>
<td>Typical C&amp;D waste</td>
<td>50 m³/1000m² (construction); 0.8 m³/m² (demolition); C&amp;D waste density is 1.6 ton/m³</td>
<td>Decision-making in recycling program</td>
</tr>
<tr>
<td>[12]</td>
<td>Massachusetts, U.S.</td>
<td>Construction, Demolition</td>
<td>Wood, asphalt shingles, carpet, drywall</td>
<td>3-5 ft²/ft² (for wood, drywall, shingles); 0.4 ft²/ft² for carpet</td>
<td>Decision-making in recycling program</td>
</tr>
<tr>
<td>[13]</td>
<td>Florida, U.S.</td>
<td>Construction, Demolition, Renovation</td>
<td>Typical C&amp;D waste</td>
<td>12-21 kg/m² (construction); 20-82 kg/m² (renovation); 595-910 kg/m² (demolition)</td>
<td>Decision-making in recycling program</td>
</tr>
<tr>
<td>[14]</td>
<td>Norway</td>
<td>Construction, Demolition, Renovation</td>
<td>Typical C&amp;D waste</td>
<td>29-31 kg/m² (construction); 574-1100 kg/m² (demolition)</td>
<td>Decision-making in recycling program</td>
</tr>
<tr>
<td>[15]</td>
<td>Thailand</td>
<td>Construction</td>
<td>Typical C&amp;D waste</td>
<td>21.38 kg/m² (residential); 18.99 kg/m² (commercial)</td>
<td>Decision-making in recycling program</td>
</tr>
<tr>
<td>[16]</td>
<td>Galicia, Spain</td>
<td>Construction, Demolition, Renovation</td>
<td>Typical C&amp;D waste</td>
<td>80 kg/m² (construction); 1350 kg/m² (demolition); 90 kg/m² (renovation) density is 700 kg/m³</td>
<td>Benchmarking</td>
</tr>
<tr>
<td>Malaysia</td>
<td></td>
<td></td>
<td>N.A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
amount of debris and the percentage of total material quantities wasted during construction process according to type of building, size of project, construction system employed, contractors' policies and waste management practice, likely sources and causes of waste. The method for calculating waste index and wastage level are as follow:

2.1 Waste Index

Waste index will help the project manager develop good planning on resources and environmental management and to reduce waste generation during all stages of a construction project. For that reason, the requirement of waste index is to identify the total amount of debris generated per GFA for each construction site.

\[ V = \text{truck volume (m}^3) \]
\[ N = \text{total number of loads for waste proposal} \]
\[ W = \text{total waste generated by the project (m}^3) = (V)N \]
\[ C = \text{Waste index} = W / \text{GFA (i.e 1m}^3 \text{area of GFA generates C m}^3 \text{of waste}). \]

2.2 Wastage Level

The purpose of calculating wastage level is to estimate the quantity of wastage from total order quantities for various materials. Based on this information, the direct cost of materials wastage and the consequent cost of waste removal and treatment, for example, sorting can be calculated for the purpose of cost control. Formula to quantify wastage level is as follows:

Cumulative order quantity
Cumulative done = (1) - (2) = wastage
Wastage Level = (3)/(2) x 100 \% (including disposed and reused materials)

3. Result and Discussion

Result from the study is presented in Table 2.

From the result presented in Table 2, it can be concluded that type of building, design, and size of project, and site management are the main factors for construction waste amount as stated by previous studies. High-end buildings with fancy and complicated facades and design, regardless of the type of building, usually produce significantly higher amount of waste. For these projects, contractors tend to commit errors especially regarding design issues such as excessive material ordering, hacking of structures due to design error or last minute design changes as previously reported [20-22]. Also, contractors tend to produce more waste due to more detailed and fine finishing. Project A, B, and C generated quite high amount of waste for relatively small projects (GFA around 10,000 m$^2$ or lower). Contrary to findings reported by Poon et. al. in Hong Kong [4, 5, 17], buildings using IBS system in Malaysia did not perform as expected, in terms of waste reduction. Project A, and B were utilizing IBS but seems did not have some correlation with waste amount. Though, projects utilizing IBS system had relatively faster completion time. According to some construction personnel in charge, the main consideration for clients choosing IBS method is completion time. Project F & G are the largest projects in this study, but project F has lower waste index due to low-rise, even though project F was the largest project featured in this study (143,600 m$^2$ of GFA). High-rise buildings such as project G, as well as project A, B, and C produce more waste due to more extensive structural and concreting activities compared to low-rise buildings (Project D, E, F, H, and I).

From company's management system point of view, it was found that there were no correlations between ISO14001-certified contractors with non-ISO14001-certified contractors on waste minimization performance. Contractors which adopted proper Waste Management Plan (WMP), and provisions on material storage and handling, as practiced on Project D, E, H and I (Table 3) performs better in terms of waste index which was similar to previous findings [5]. WMP is likely to put waste issue on the map. Interviews with construction personnel revealed that improper handling and storage, lack of
supervision, and poor workmanship are frequently common causes of waste generation. WMP also encourages reuse and recycling program to be implemented. From projects survey and interview sessions, steel reinforcement bar and other metals such as scaffolding and ceiling brackets are the only materials that worth to be salvaged (for recycling purposes). Timber is usually reusable up to four times before eventually disposed. Most contractors have already practiced this. Project H is the only one which practiced on-site waste segregation with detailed waste accounting and record-keeping to keep track on reuse and recycling program while attempting other effective measures to avoid and minimize waste as reflected by quite low waste index figure (Table 2). Overall environmental performances of Project H were also astonishing as this was a Green Building-Certified project. Unfortunately, there was lack of awareness among contractors in practicing waste sorting and waste accounting, let alone recycling program for non-metal materials. Project D which did not adopt any WMP or any similar provision surprisingly performed well in terms of waste generation. This was a rare exception which is mainly due to practice of open burning (especially timber and packaging waste) and buried concrete waste especially from piling (this was

| Table 2 Waste index and wastage level for various sites in Klang Valley. |
|-----------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Project         | A         | B         | C         | D         | E         | F         | G         | H         | I         |
| Contractor      | X         | X         | X         | Y         | Z         | X         | X         | W         | V         |
| CIDB Grade      | G7        | G7        | G7        | G7        | G7        | G7        | G7        | G7        | G7        |
| Type of building| Commercial (office) 39 storey | Residential 7 blocks, 21 storey, 105 unit | Commercial 30 storey | Commercial (Education), 4 storey | Commercial (Education), 12 storey | Commercial 4 storey | Residential (Condominium) 8 storey | Commercial (office) | Low Rise Education Building, 6 storey |
| Method          | IBS (fwork system by PIERI) Wall, climbing system | Conventional (plywood) | IBS (fwork system by PIERI) Wall, column, slab, propping, climbing system | Mostly conventional, small portion using framework for columns | IBS (precast panels as permanent fwork from PIERI) fwork system for slabs from Kumbang. |
| Waste index (m²/m³) | 0.4702 | 0.2479 | 0.1494 | 0.0339 | 0.0488 | 0.1087 | 0.1497 | 0.0510 | 0.06804 |
| Wastage Level   | Rebar 36% concrete 0% | Rebar 4.98% concrete 4.99%, timber 100% | Rebar 5.15% concrete 10.54%, timber 100%, bricks & blocks 5.19%, plaster 8.03%, tiles 8.00% | Rebar 10.34% concrete 10.20%, timber 100%, bricks 4.87%, cement 3.36%, tiles 3.20% | Rebar 5.71% concrete 5.26%, bricks & blocks 3.63%, timber 100% | Rebar 9.63%, concrete 4.11%, bricks 5.06%, blocks 5.23%, cement 1.59% | N.A. | Rebar 7.69%, concrete 1.01%, timber 9.77%, bricks & blocks 3.45%, plaster 8.69%, tiles 7.17% |
| Waste Management| Rebar & metals were reused & salvaged, cement packaging returned to supplier | Rebar & metals were reused & salvaged, cement packaging returned to supplier | Rebar & metals were reused & salvaged, some concrete waste buried, timber reused & burnt | Rebar & metals were reused & salvaged, some concrete waste from piling buried | Rebar & metals were salvaged, | Rebar & metals were salvaged, | Green Building Certified; use of sustainable materials, waste minimization & avoidance program, waste sorting, detailed record-keeping, reuse & recycling for concrete, cardboard, plastic | Rebar & metals were reused & salvaged, concrete waste reused & some are recycled |
| Lifespan of materials | Steel → 3-4 times; Formwork system → 10-15 casting | Steel → 3-4 times; Formwork system → 10-15 casting | Timber → 2-3 times | Timber → 2 times | Timber → up to 4 times | Timber → up to 4 times | Timber → 4-6 times | N.A. | Timber → 5-6 times, some recycled |
also practiced on Project E). While these practices may reduce the actual amount of waste to be disposed at landfills and save some cost on disposal trips, but they would cause greater negative impacts on environment.

Overall, waste index and wastage level figures in Malaysian construction industry are still vary, all over the place, some with significant contrast. Result shows that construction waste generation rate benchmarks in Malaysia are still not up to mark. Wastage level for major materials in some projects may reach up to 10%. Baseline values among Malaysian contractors are yet to achieve the standard benchmark of 4-5% wastage level as suggested by previous studies [2, 4, 17]. Currently, there is still relatively lack of waste minimization awareness among construction players in Malaysia as reflected by poor waste record-keeping, lack of waste sorting and recycling practice, low usage of IBS systems, and lack of supports from top management, clients, and authorities.

4. Conclusions

Based on the findings, overall site-management, size of project, and awareness of waste management among construction personnel which supported by top management and clients (as displayed by adoption of WMP, material storage and handling SOP, and Green Building Certification) are the most significant factors that contribute to construction waste generation. Types of buildings and construction method employed do not have strong correlation with waste amount, although IBS system and residential-type building have shown have the tendencies to produce less waste, in conditioned with excellent on-site management, supervision, and quality control. Design-associated errors, poor handling and storage, poor workmanship, cut-offs (residuals), and technical errors are among the most common source of waste. While formwork, concrete casting, and finishing trades are among construction activities that produce significant amount
of waste. On-site waste sorting and quantification are the most effective waste management measures to help ease reuse, recycle. Construction waste quantification and benchmarking can serve as tools to evaluate the current status of waste generation, effectiveness of waste reduction and loss prevention measures, and overall site management. The roles of construction authorities are essential in achieving the desired benchmark in waste generation rate for Malaysian context. Construction authorities as the policy maker and enforcer could develop and issue new regulations or incentives to stimulate and encourage waste management practices and the use of green building technology, establishing formally standardized systems in record-keeping of quantitative data, introduce useful guidelines and measures, conduct education and training to achieve sustainability and better environmental awareness among Malaysian construction players. Enforcement is essential to ensure that the requirements and standards are fulfilled.

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