The impact of green building accreditation on construction and demolition waste minimization: A study of Hong Kong Building Environment Assessment Method (HK-BEAM) using big data

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Abstract

Construction and demolition (C&D) waste often constitutes a prodigious portion of the total municipal solid waste in contributing to the environment degradation. C&D waste minimization, which is a sustainable activity for both environment and material resources, serves as an indispensible element of green building assessment systems worldwide. How green building accreditation impacts on C&D waste minimization is a valid and important research question for green building award applicants, policy-makers and other stakeholders, which was seldom studied using a quantitative approach. Therefore, this paper aims to quantify the waste minimization which existing green building assessment system can be used to achieve by analyzing a big dataset of C&D waste management recorded in 2011, 2012, 2013, 2014 and 2015 in Hong Kong. The waste generation rates are compared between buildings awarded with and without Hong Kong Building Environment Assessment Method (HK-BEAM) prizes to illustrate the impact of HK-BEAM on C&D waste minimization. The research findings will not only present accurately quantified effect on CWM led by green building accreditation, but also provide stakeholders with a reference for making strategies and policies on C&D waste management and green building.

Introduction

Construction activities have led to a considerable amount of construction waste worldwide. In United States, the building-related waste generation amount in 2003 was estimated to be 170 million tons, with 15 million tons for construction, 71 million tons for renovation and 84 million tons for demolition (EPA, 2009). European Commission (EC) reported the C&D waste is responsible for 25%-30% of all waste generated in the European Union (EC, 2015). Statistics show that solid waste ending up in Hong Kong landfills reached 14, 311 ton per day (tpd) in 2013, of which 25% or 3,591 tpd was from construction activities (Hong Kong Environment Protection Department [HKEPD], 2015a). Meanwhile, there have been warnings that the landfills in Hong Kong, planned to last until 2020, could be full several years earlier if nothing is conducted to reduce waste loads (HKEPD, 2015b). The promotion of sustainable development has exerted the demand for proper methods to focus on waste minimization in construction industry.

Management strategies and technologies have been studied so as to tackle the existing construction waste problems. From management perspectives, Poon et al. (2001) suggested enacting contractual requirements or legislation to make on-site waste sorting a long-term solution to the landfill shortage. Shen et al. (2004) developed a waste management mapping model, which assists in planning waste management procedures on construction sites. Lu and Yuan (2013) suggested the application of offshore prefabrication, which could lead to around 2% construction waste reduction. Osmani et al. (2008) recommended waste minimization design, which could lead to about one-third of construction waste. In addition, Wang et al. (2014) identified six critical factors that significantly influence the waste minimization at design stage. Technically, integrated GPS and GIS technology was investigated and found effective in minimizing the amount of onsite material wastage (Li et al., 2005). In addition, viable technologies on construction waste recycling were also reviewed by Tam and Tam (2006). Echoed with academia, Hong Kong governments also formulated relevant policies to promote construction waste minimization, among which, the Construction Waste Disposal Charging Scheme enacted since 2005 (HKEPD, 2015c) has been proved to be effective for construction waste reduction (Lu and Tam, 2013). Although numerous management strategies and technologies have been tested effective in C&D waste minimization, previous studies seldom investigated how one of the existing practices, green building accreditations where the requirements for waste minimization is an indispensible part impact on construction waste minimization.

This paper quantifies the waste minimization which existing green building assessment systems can be used to achieve. The study starts with hypotheses of the relationship between green building accreditation and waste generation rate (WGR), which is a key performance indicator for C&D waste management. Then, the WGRs are compared between buildings awarded with and without Hong Kong Building Environment Assessment Method (HK-BEAM) prizes to illustrate the impact of HK-BEAM on construction waste minimization by analyzing a big dataset of CWM recorded in recent five years. The impact of green building accreditation on construction waste minimization is discussed based on the results from the comparison.

Objectives

This paper aims to examine the impact of green building accreditation on the waste minimization in demolition and construction projects respectively. In addition, the research also examine whether the waste minimization rate increase with the prize level awarded by the green building accreditation organization. Hopefully, the study result will become a reference for the policy making and other stakeholders in C&D waste management.

Literature review

Green Building and Green Building Accreditation

Green buildings are nowadays well embraced due to the diversified benefits that can advance the sustainable development. From the perspective of environmental protection, green buildings, for instances, help enrich the biodiversity and protect the ecosystem through sustainable land use (Herry and Frascaria-Lacoste, 2012; Bianchini and Hewage, 2012), and could reduce a large amount of green house gas emission (Jo et al., 2009).

Economically, the application of green buildings may cut down the life cycle cost (e.g., carbon trade cost and high energy cost) (The Economist, 2004; Zuo and Zhao, 2014), although extra cost is required for the construction of green buildings. Green building also brings social benefits, such as improving health conditions of the residents and social productivity (Singh et al., 2011; Pan et al., 2008), enhancing people's aesthetic appeal and bringing comfort for occupants (Zhang and Altan, 2011). For the sake of the above-mentioned benefits through the use of green buildings, the missions of promoting the application of green buildings drive the launches of green building accreditation schemes in successions across countries.

Green building accreditation schemes can generally be identified as third-party certification programs and comprehensive benchmarks for design, construction, operation and measures of a building's environmental performance (Council, 2008; BREEAM, 2015; HKGBC, 2015). Green building design requires designers to go beyond the codes to improve overall building performance, and minimize life-cycle environmental impact and cost (Gowri, 2004). Green building accreditation schemes developed in different countries. The first scheme was the Leadership in Energy and Environmental Design (LEED) program, launched by the USGBC in 2000. A year later, the Building Research Establishment published the Building Research Establishment Environment Assessment Methodology (BREEAM). In 2003, the Green Building Council of Australia (GBCA) formed Green Star as the only national and voluntary building rating system. The Chinese Green Building Label (GBL) was developed by China Building Science Research Institute in 2006. Up till now, there are no universal principles or international standards of green buildings recognized, different scholars and researchers intend to classify the principles and elements of green buildings into different domains. Details of these schemes may have differences, but there are at least five major elements that should be taken into account in green building design: sustainable site design, water conservation and quality, energy and environment, indoor environmental quality, and conservation of materials and resources (Zeigler, 2002).

Among these major elements, sustainable site design, and conservation of materials and resources seem closely related to CWM, which is therefore an indispensable element evaluated with credits in different green building rating systems. Various schemes arising from different conditions mainly including the local climate and regional development level have different foci and requirements on construction waste management (Wu et al., 2015). However, few studies ever dealt with problem of how the schemes have impact on the performance of CWM in a quantitative way. The Building Environmental Assessment Method (HK-BEAM) scheme was established in 1996, largely based on the UK Building Research Establishment's BREEAM (Prior, 1993). There was a significant upgrade to the previous BEAM documents in 2004 (Building Environment Council, 2004). In 2009, in response to the critical global environmental issue, BEAM was further developed to BEAM Plus Version 1.1 to meet higher expectations of the public and community. In 2012, BEAM Plus for new and existing buildings were launched, which is the latest versions of HK-BEAM (BEAM Society, 2012). HK-BEAM has been employed to assess the most square meters of buildings across the world (Lee

and Burnett, 2008). The impact of HK-BEAM on CWM is selected as the first step to tackle with this problem in this study.
in this study.

Construction waste management

Construction activities not only consume a large amount of natural resources, materials and energy, but also generate unacceptable level of solid waste (Yuan et al., 2012). Construction waste often constitutes a prodigious portion of the total municipal solid waste in contributing to the environment degradation [9-12]. Owing to its non-combustible nature, construction waste normally ends at landfills. In the United Kingdom, for example, more than 50% of waste deposited in a typical landfill come from construction [13]; while about 70 million tons of waste are arisen from construction and demolition activities [14]. In Australia, about 14 million tons of waste have been put into landfill each year, and about 44% of waste are attributed to the construction industry [15, 16]. In the United States of America, around 29% of solid-waste are from construction [17]. Waste in landfill leads to extensive amounts of air, water and soil pollution due to the production of CO_2 and methane from anaerobic degradation of the waste. During the past decades, construction waste has received increasing attention from both practitioners and researchers around the world (United Nations Centre for Human Settlements, 1990; Ofori, 1992; United Nations Centre for Human Settlements, 1993; Lenssen and Roodman, 1995; Worldwatch Institute, 1995; Bossink and Brouwers, 1996; Brown *et al.*, 1996; Poon *et al.*, 2004; Tam, 2008a; Lu and Yuan, 2011). Construction waste often constitutes a prodigious portion of the total municipal solid waste (MSW) in contributing to the environment degradation (Boiral and Henri, 2012; Coelho and de Brito, 2012; Comoglio and Botta, 2012; Yuan et al., 2012). For example, the latest statistics from Hong Kong Environmental Protection Department (2014) showed that all waste received at landfills reached 13,844 tons per day (tpd), or 5.05 million tons a year, of which about 25% is construction waste. Ton means metric ton throughout this paper if not otherwise stated. It is reported in Mainland China construction produced more than two billion tons of construction waste in 2011 (Ramzy, 2013), and it is generally estimated that construction waste takes up around 30-40% of total MSW in China (Qiu, 2010). Hyder Consulting (2011) reported that a total of 19.0 million tons of construction and demolition (C&D) waste was generated in Australia in 2008-09; of this total waste stream, 8.5 million tons was disposed to landfill while 10.5 million tons, or 55%, was recovered and recycled. Eurostat (2014) estimated that a total of 857.2 million tons of construction waste was generated in the EU-27 Member States in 2010. In this paper, Europe refers to EU-27 member countries in the European Union, including Belgium, France, Germany, Italy, Luxembourg, Netherlands, Denmark, Great Britain, Ireland, Portugal, Spain, Greece, Austria, Finland, Sweden, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Malta, Cyprus, Bulgaria and Romania. Construction took up about 15% of all waste landfilled, while MSW was about 37% (Eurostat, 2014). Department for Environment Food & Rural Affairs (2014) in the United Kingdom reported that total construction waste generated in 2010 in England was 77.38 million tons. In the United States, the United States Environmental Protection Agency (2009) estimated that approximately 170 million tons of building-related C&D materials were generated during 2003. a

There are two generic approaches for dealing with construction waste. From a technical point of view, environmental engineers investigate how "hard" technologies can help reduce, reuse, or recycle construction waste, i.e. through introduction of prefabrication, using metal formwork, and using recycled aggregate for different concrete applications. By appreciating that construction waste is also a social issue, "soft" economical or managerial measures have gained momentum.

Although C&D waste is often included as one of the forms of municipal solid waste (MSW), C&D waste is considered heterogeneous when compared to general MSW (e.g. household waste) or other industrial solid waste (ISW) (e.g. hospital waste or electronic equipment) (Lu et al., 2011). Construction is an environmentally unfriendly activity. Its waste often constitutes a prodigious portion of the total MSW that contributes to degradation of the environment (Lu and Tam, 2013, Boiral and Henri, 2012 and Coelho and de Brito, 2012).

Development of Hypothesis

1. Hypothesis 1 (H1): The CWM performance of green building accreditation certificated buildings is better than ordinary buildings, which is reflected by the overall WGR of BEAM certificated projects are lower than the overall WGR of ordinary projects.
2. Hypothesis 2 (H2): The CWM performance of green building accreditation certificated buildings are in the order of Platinum, Gold, Silver and Bronze, which will be reflected by their WGR.

Research Design

Data and Sources

Until early 2015, BEAM plus has accepted the registration of 616 projects, the name and address of which are published online. A rating is issued to an assessed project according to the attained credits: Platinum, Gold, Silver, Bronze, or Unclassified. The distribution of the assessed projects is shown in Table 1. To effectively manage C&D waste, a Construction Waste Disposal Charging Scheme (CWDCS), which has come into in Hong Kong since December 2005. C&D works conducted in Hong Kong are required to open a billing account for afterward construction waste disposal records by noting down the details of the work to be conducted. There had been 26,566 billing accounts opened until 2 September 2015. For a construction project carried out by several contractors, there are several accounts for different types of works, including demolition, foundation and building, while some projects as a package deal might only have one account for all types of works. HKEPD have been recording the waste disposal information comprising account number, waste weight and other information of every lorry of C&D since the establishment of CWDCS. This study mainly relies on these second-hand data records. Until end of June 2015, this scheme had led to the generation of 5,871,539 waste disposal records at the Hong Kong Environment Protection Department (HKEPD). It can be seem in Fig. 1 the three database can be connect based on the account number.

Table 1 Distribution of BEAM assessed projects

Result	Platinum	Gold	Silver	Bronze	Unclassified
Number	35	62	35	42	77

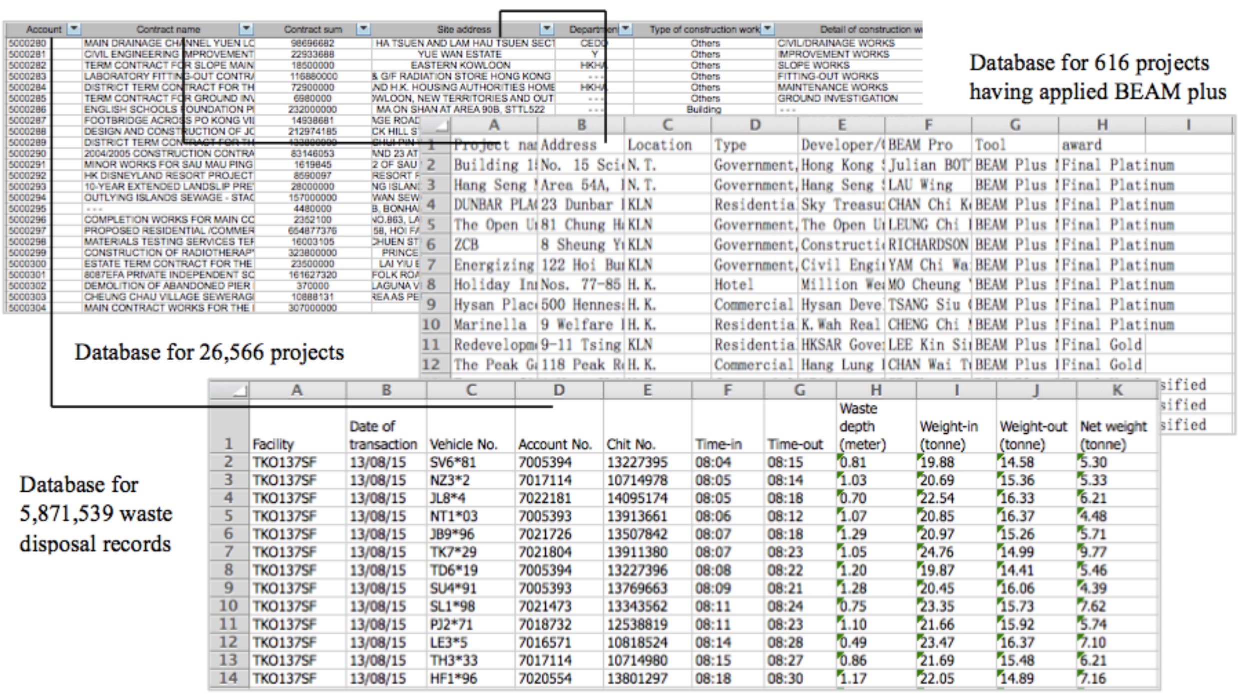

Fig. 1 Connections between databases for billing account information, BEAM plus projects details, and waste disposal records

Data Analysis

1. Connecting BEAM projects database and billing account database

The first step is to connect the databases in Fig.1. This study tried to use automatic match between BEAM projects database and billing account information database using the following algorithm:

(1) All the spaces and punctuations in the site addresses and contract name in both BEAM projects database (File 1) and billing account details (File 2) are deleted.

(2) Any site address or contract name becomes an ordered set made of characters, i.e. a site address and a contract name for project i in File 1 is Ai and Bi respectively, a site address and a contract name in File 2 is C_j and D_j respectively.

(3) The site addresses in File 1 are used to match the site addresses in File 2. The same is done for the contract name. If A_i include C_j or C_j include A_i, or B_i include D_j or D_j include B_i we think i and j could possibly be the same project. i and j are preliminary matched. There are more than 1,000 matched records.

4) All the preliminary matched projects are manually checked, and actually unmatched projects and repeated projects are deleted.

5) Finally 24 projects were finally matched.

2. Estimating WGRs of BEAM assessed projects and ordinary projects

This study analyzed the waste generation rates (WGRs) of the BEAM assessed projects using the big dataset and the relevant databases shown in Fig. 1.Since the attainable credits for demolition waste reduction and construction waste reduction are set separately in the assessment, the WGRs of demolition and construction are measured separately. For demolition work alone, the corresponding billing account should only include demolition type, while construction works includes more kinds of works, mainly foundation and building. For demolition of a project, the WGR is calculated in Equation (1). For construction of a project, the WGR is calculated in Equation (2)

$$WGR_d = \frac{\text{total waste amount by weight}}{\text{contract sum}} \quad (1)$$

$$WGR_c = \frac{\text{total waste amount from foundation + total waste amount from demolition}}{\text{contract sum of foundation +contraction sum of demolition}} \quad (2)$$

Big data in C&D waste management has shown a picture that the distribution of WGRs of a large number of construction projects is similar to a lognormal distribution rather than a normal distribution (Lu et al., 2015; Chen et al., 2015). Therefore, this study select median of a set of WGRs as a representative value to reflect the waste generation of that set of construction projects.

This study first measured the overall WGR of demolition work and overall WGR of construction work for BEAM classified projects (i.e. Classified overall in Tables 2 and 3). Then, the WGRs of ordinary projects, which exclude the assessed projects, are measured as well to testify H1. In order to testify H2, the waste management performance of Platinum, Gold, Silver Bronze and Unclassified BEAM assessed projects are calculated separately and shown in Tables 2 and 3 for demolition and construction works. It can be seen in Table 2 the demolition WGRs is in accordance with both H1 and H2, while Table 3 gives evidences to reject both H1 and H2. For demolition on one hand, the WGRs of projects with various results from platinum to unclassified increase smoothly. The classified overall WGR is obviously less than WGR of ordinary projects. Beside, unclassified projects have less WGR than ordinary projects. On the other hand, no patterns can be found in the WGRs of construction works. Overall, it is obvious that the WGRs for demolition are higher than those for construction works to a large extent.

Table 2 Median WGR (t/mHK$) of demolition works

Type	Platinum	Gold	Silver	Bronze	Unclassified	Classified overall	Ordinary
WGR_d	255.56	322.01	384.38	457.55	508.43	340.48	588.36

Table 3 Median WGR (t/mHK$) of construction works

Type	Platinum	Gold	Silver	Bronze	Unclassified	Classified overall	Ordinary
WGR_c	57.65	29.20	34.12	48.69	29.19	43.64	34.33

Discussion

1. Demolition waste reduction explanation

The waste management of overall BEAM awarded projects performs better than ordinary projects, because the WGR of former accounts for only 57.87% of the latter, which can be interpreted as 42.13% demolition waste minimization can be achieved in a project with the promotion of BEAM plus award. In BEAM plus, it is not only required to conduct a demolition waste management plan, but also two attainable credits are allocated for demolition waste recycling. For more than 30% demolition waste recycling, an assessed project can obtain one credit; for more than 60% recycling, the project can obtain two credits. The waste management plan and the credits for demolition waste recycling may be the reason that demolition waste management for the classified projects are largely performed better than ordinary project. For different results from platinum to unclassified, the demolition waste are managed in the order of best to worst, because contractors pay more efforts to get any credits, including demolition waste reduction in the green building scheme. The requirements for the credits may be easy to meet, because the waste generation from a demolition work is of tremendous amount, where over 90% of waste materials are inert waste with large potential for recycling (HKEPD, 2015). Nevertheless, BEAM might not be the only cause of the pattern of WGRs, waste reduction can also bring economic benefits for contractors, including the materials purchase cost, waste transportation cost, and waste disposal cost.

2. Construction waste reduction explanation

Though construction waste management plan is required and construction waste reduction is allocated with two credits as well, the waste management performance failed to show similar pattern with demolition waste management. As BEAM is not the only reason for demolition waste reduction, the no pattern for construction waste management performance can be explained by comparing the natures between demolition waste reduction and construction waste reduction. For ordinary project, the demolition waste generation can be roughly estimated as over 17 times of construction waste generation. Because the amount of demolition waste is large, contractors may think it is worthy to take actions to sort and recycle the demolition waste, and reuse the waste materials at a large scale. It is evident that the most important motivation for contractors to conduct waste reduction is economic profits, followed by BEAM credits. Once the recycling actions are taken, they may pay great efforts. Then, the recycling technologies may come into effect: the better recycling work, the higher award.

Conversely, the construction amount is small, which makes contractors may pay less attention to it due to far less economic profits to take such inconvenient actions. When few projects adopt construction waste recycling, it is understandable the construction waste management performance shows no specific pattern in Table 3. Another reason could be it is more difficult to conduct construction waste reduction than demolition waste reduction because nowadays the widely adoption of prefabrication has reduced the amount of recyclable construction waste. Even though construction waste is far less than demolition waste, its impact to the environment is also considerable. Strategies are needed to stimulate the reduction of construction waste. On-site sorting activities are crucial for waste reduction. With no obvious economic benefits, building construction participants are reluctant to carry out on-site waste sorting (Poon et al., 2001). Legislations can make on-site waste sorting no matter for construction works be fully implemented. In addition, with advanced construction material, technology and management, the construction waste may be naturally of low generation rate. For example, the construction works with and without prefabrication provisions should be treated differently in the requirements of the attainable credits in construction waste reduction. It is noticed that in BEAM, unlike site aspects, energy use, and indoor environment quality, material aspect where waste reduction are mainly in, the grade of which is only counted in overall grade but not required separately (HKGBC, 2015). It means BEAM allocated very few weighting for demolition and construction reduction. Therefore, BEAM should put a high value to demolition and construction waste reduction, due to its serious degradation to the environment.

Conclusions

This study examines the impact of green building accreditation on C&D waste management performance by comparing the WGRs between BEAM awarded project and ordinary projects, and the WGRs between projects of different BEAM awards. Data analysis is relying on a big dataset of waste disposal records, a database for billing account, and a database for BEAM registered project. The data analysis shows that demolition waste management performance can be improved with the involvement of BEAM awards, and projects with higher awards perform better than those with lower awards. However, the construction waste management performance shows no specific pattern along with the change of assessment results. The results indicate the precondition for construction participants to conduct on-site sorting and recycling is economic benefits. Under this precondition, the performance of waste management follows the rule of paying more efforts to gain more BEAM credits. The profitable nature of demolition waste recycling has driven contractors to conduct waste recycling works, while the relatively small amount of construction waste makes recycling of it have little economic profits. Strategies are raised such as forcing legislations to restrict on-site sorting activities, treating projects applied with advanced construction materials, technology and management differently in construction waste reduction, and BEAM should pay more attention to waste management. This study not only reflect the real impact of BEAM for C&D waste management, it is also a reference for policy makers to upgrade their practices in C&D waste management and green building.

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