A COST-BENEFIT ANALYSIS OF GREEN BUILDINGS WITH RESPECT TO CONSTRUCTION WASTE MINIMIZATION USING BIG DATA IN HONG KONG

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ABSTRACT

It is generally accepted that the extra construction costs involved in the construction of green buildings will result in benefits including lower operation costs, higher sale/rental prices, and better sustainability performance. However, there has been little recognition of construction waste minimization (CWM) as one of the important benefits of sustainability performance as designated in green building. This paper aims to provide a better understanding of the cost benefit of green buildings with respect to CWM by using big data in the context of Hong Kong. The study is innovative in that it conducts a cost-benefit analysis specifically on CWM of green buildings by mining large-volume datasets. A surprise finding is that Hong Kong's green building rating system (GBRS), i.e. the BEAM Plus, has a negligible effect on CWM, while it generally increases construction costs by approximately 24%. Hence, the increased construction cost of green buildings cannot be offset by CWM if corresponding items in the BEAM Plus are not properly incentivized. This paper demonstrates the necessity of emphasizing CWM-related items in GBRSs and of taking appropriate measures to deal with them. It also provides better decision-support information on the increased construction costs and the attainable benefits of green building that developers may wish to consider when initiating a green building project.

KEYWORDS

green building, cost-benefit analysis, construction waste minimization, big data, Hong Kong

1. INTRODUCTION

Green building is becoming an important element of the built environment worldwide. It is promoted to address major contemporary challenges such as natural resource depletion,

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pollution, greenhouse gas emissions, and human-induced global warming. Here, building is cleverly used as a polysemy; it refers to both a noun to represent a physical building structure and a gerund to describe the building activity. It is generally recognized that extra construction costs would be spent on green building compared with regular buildings, as 'going green' often needs more expensive materials, facilities, technologies, and acquiring new expertise (McAllister, 2012; Lu and Yuan, 2013). For sustaining the economic legitimacy of green building, the extra construction costs must be offset by higher economic and/or sustainability benefits at a later stage. Numerous cost-benefit analyses (CBAs) have been conducted to ascertain whether the projected economic/sustainability benefits have truly been attained in buildings awarded a green building certificate. Some studies have found that the results are largely positive (e.g. Newsham et al., 2009; Menassa et al., 2011; Gou et al., 2013), while others have reported unfavourable findings (e.g. Scofield, 2009).

Construction waste minimization (CWM) is one of the important benefits that are stipulated in most green building rating systems (GBRSs). Construction waste, also called construction and demolition (C&D) waste, is responsible for a large proportion of total solid waste (HKEPD, 2015a). Owing to its non-combustive nature, C&D waste is normally landfilled, which often leads to extensive amounts of air, water, and soil pollution due to production of CO_2, methane, and leachate. Landfilling will also deplete valuable landfills quickly. For example, Hong Kong has suffered from a rate of about 3,500 m^3 per day of landfill space depletion (Poon et al., 2001). Recent data shows that Hong Kong landfilled 4,200 tonne of construction waste per day in 2015 (HKEPD, 2015a), and is faced with all existing landfills being filled by 2020 (HKEPD, 2005; GovHK, 2017). In fact, only a very small proportion of construction waste, which is non-inert, needs to end in landfills (HKEPD, 2015a). Construction waste reuse and recycling have become a worldwide task, but in previous studies, little attention has been paid to achieving CWM along with the promotion of GBRSs.

To address the problems identified above, this paper examines whether the extra construction costs driven by GBRSs has been well spent in terms of CWM performance improvement by conducting a CBA. As a precondition of the CBA, the paper first examines the existence of extra construction costs involved in pursuing green buildings. A CBA of GBRSs, specifically with respect to CWM, is then conducted by taking advantage of a large-volume dataset from Hong Kong's green building movement, construction waste management practices, and building statistics. The remainder of the paper is organised as follows: section 2 provides a literature review of the extra construction costs for green buildings and cost benefits, with a focus on CWM; sections 3 and 4 are the methodology and data descriptions respectively; section 5 presents an analysis of the cost benefit of GBRSs with respect to CWM using empirical data; and sections 6 and 7 discuss the results and draw conclusions respectively.

2. LITERATURE REVIEW

This section conducts a literature review regarding the extra construction costs of green buildings. Then, the status quo of CWM is presented for identifying the importance of effectively implementing CWM through promoting GBRSs. The benefits that can offset the extra construction costs of green buildings are reviewed from a CBA perspective with a view to establishing the necessity of studying CWM benefits instead of focusing solely on cost rewards.

2.1 Extra construction cost of green building

The development of green buildings goes beyond traditional codes of practice by demanding a higher and voluntary standard for achieving sustainability performance. The widely propagated benefits of green buildings include lower operation costs (Gowri, 2004; Olanipekun et al., 2018), higher rental/sale prices (Kats, 2003), the enrichment of biodiversity and protection of the ecosystem (Bianchini and Hewage, 2012), reduction of greenhouse gas emissions (Shuai et al., 2018), energy saving (Cheng et al., 2011) and improved health conditions for occupants and greater social productivity (Zhang and Altan, 2011). GBRSs provide voluntary frameworks containing criteria that a green building should meet.

Since the emergence of green buildings, a growing body of literature has been focusing on the costs involved in their design and construction. Many building professionals argue that green buildings can result in higher construction costs, a contention that researchers have largely confirmed. For example, studies have found that an extra construction cost of 3–15% is required for developing a green building, depending on the region and the applied GBRS (Bartlett and Howard, 2000; Miller et al., 2008; Langdon, 2007). Quantity surveyors in the UK have claimed that more energy efficient and environmentally friendly building cost between 5% and 15% more to build from the outset, although this number has been questioned (Bartlett and Howard, 2000). Miller et al. (2008) estimated the extra construction cost for LEED at 7–11% for Platinum, 3–7% for Gold, and 1–4% for Silver, depending on the region; and Langdon (2007) estimated the extra construction costs for achieving Green Star to be in the order of 3–5% for a 5-star solution, and more than 5% for a 6 star non-iconic design solution.

Different economies will have disparities in the extra costs for green building. As this study is contextualized in Hong Kong, the extra cost is calculated to contribute to the knowledge of the price for "going green" in that jurisdiction, where the Building Environmental Assessment Method (BEAM) (currently BEAM Plus) is the dominant GBRS. This study takes advantage of second-hand, objective data to calculate the extra construction cost of BEAM-driven buildings and therefore to investigate the extra construction cost for green building in Hong Kong, while additionally providing credible information for the reference of stakeholders, such as developers, researchers, and consultants.

2.2 CWM as an important benefit of green building

Many studies have assessed the life-cycle cost of green buildings to determine whether the extra construction costs can be offset by economic or sustainability benefits, such as energy saving, less material waste, and water saving in the later stages of a building's life cycle. CWM is one of the frequently-cited benefits. Construction waste is defined as the surplus and damaged products and materials that arise from construction, renovation, and demolition activities (Roche and Hegarty, 2006). Construction waste often constitutes a significant portion of the total solid waste, which primarily consists of municipal solid waste (MSW), construction waste, and special waste (Lu et al., 2017; HKEPD, 2015a). In the U.S., the amount of C&D waste generated in 2014 before recycling has been estimated at 534 million tons, which is twice the amount of MSW generated in that year (USEPA, 2016). The European Commission (2013) reported that construction waste is responsible for 25–30% of all waste generated in the European Union. According to *Monitoring of Solid Waste in Hong Kong: The Waste Statistics* for the ten years from 2005 to 2015, the percentage of construction waste generated in Hong Kong was about

23–28% of the total solid waste (HKEPD, 2015b). In Japan, construction waste contributes 20% of the total solid waste generated by all industries (MoE, 2014). Construction waste is primarily in two mainstreams: non-inert waste and inert materials (Lu et al., 2016a). At present, most non-inert construction waste ends up in landfills rather than being incinerated or recycled. However, landfilling waste has caused considerable air pollution (Chang et al., 1996), water (Mor et al., 2006), and soil (Garcıa-Gil et al., 2000). Landfills also take up valuable areas of compact cities such as Hong Kong and Singapore (Lu and Tam, 2013; Lu et al., 2016b; Chen and Lu, 2017).

As a response to the negative environmental impacts of construction waste, CWM is one of the most important environmental issues stipulated in various GBRSs. On average, CWM-related initiatives account for roughly 10% of the total points awarded in the prevailing GBRSs, e.g. LEED (10%), BREEAM (8.16%), Green Globes (11.5%) and Green Building Index (8%) (Wu et al., 2016). However, there is no reliable empirical evidence concerning the effect of such schemes on CWM. Allowing CWM efforts to account for 10% of all points awarded in a GBRS without concrete evidence of their effect not only constitutes a significant knowledge void but also poses problems for green building development. The effects of green building certification on CWM are a common query in various stakeholder engagement exercises, but the answer is either not forthcoming or it is ambiguous. Without knowing their real effects, CWM-related points may be surrendered to other green initiatives, such as energy efficiency or water conservation, with almost certain knock-on effects to investors, owners, designers, consultants, and contractors.

2.3 Lack of CBAs of GBRSs targeting CWM

Although CWM is one of the multiple cost benefits of green buildings, it has never been examined using empirical data. An important consideration for green building acceptance is that the extra construction costs involved can be offset by benefits at a later stage, e.g. throughout the building lifecycle (Zuo and Zhao, 2013). The benefits of green buildings can be classified as two types: economic benefits and sustainability benefits. The GBRS-driven economic and sustainability benefits, such as energy saving, cost saving, and improved life quality (Cheng et al., 2011; Zhang and Altan, 2011) are well understood from previous studies, but CWM as an important cost benefit remains somewhat of a mystery. By using large datasets from the green building movement and CWM practices in Hong Kong, this study examines whether practitioners have effectively accomplished CWM in accordance with GBRSs' original intention.

3. METHODOLOGY

This section presents the methodology of the study based on the research aim and objectives. Hypotheses are proposed for testing with quantitative analysis, and a GBRS is selected and described as the basis for analyzing the relationships between green building, construction costs, and CWM. Finally, the methods used for testing the hypotheses are presented.

3.1 Hypotheses

This research defines a GBRS-driven project as a project that has achieved a GBRS certification, been unclassified, or just registered for green building accreditation at the time of data collection. A non-GBRS-driven building is referred to as a regular building in this study. Considering that all the recognized GBRSs include the scope of CWM, it is hypothesized that:

H: GBRS-driven buildings cost more but perform better in CWM than regular buildings.

There are actually two interconnected hypotheses: one posits that GBRS-driven buildings cost more than regular buildings (H_1) and the other posits that GBRS-driven buildings generate less construction waste than regular buildings (H_2). It is emphasized here that construction costs often include the land cost and construction cost. However, this study does not consider the former, as land cost barely matters in relation to green features, and could go extremely high in some land-scarce cities to distort the building cost formula. For construction cost, this study investigates the main stages of foundation and building, otherwise known as substructure and superstructure.

3.2 GBRS in focus: BEAM Plus

Hong Kong's BEAM Plus has the common scopes of energy saving, water conservation, site selection, building materials, and indoor environmental quality as other GBRSs (Cole, 2003; Wu and Low, 2010; Wu et al., 2016; Li and Yang, 2014). Due to its well-recognized effectiveness in the green building movement and full recording of the projects involved, this study used BEAM Plus as the representative GBRS to test the hypotheses. BEAM Plus is the most recent version of Hong Kong BEAM that was first launched in 1996. As a result of having evolved in response to the needs of the local built environment over two decades, BEAM Plus was established in November 2012. It has a similar scope to UK BREEAM (Prior, 1993) and groups the green features of a building into six aspects: Site, Energy Use, Indoor Environmental Quality, Materials, Water Use, and Innovations and Additions. CWM-related items are mainly in the Materials aspect.

Buildings assessed by BEAM Plus may be issued an Unclassified, Bronze, Silver, Gold, or Platinum label, or simply be recorded as "registered" for BEAM Plus certification. All BEAM-driven buildings are considered as the sample in this study. Certain buildings grouped as regular might have also achieved a higher performance of CWM performance, or cost more than some BEAM-driven buildings, owing to other factors. Examples of better CWM performance are that a regular building was constructed according to other GBRSs, or a regular building developer skilfully managed the materials. Although such projects exist, they are in a minority among regular projects. As no two buildings are totally the same, this study avoids a case versus case comparison and instead conducts a group versus group comparison. Accordingly, this study compares the CWM performance and cost between a group of BEAM-driven buildings and a group of regular buildings. As a result of using a considerable number of buildings instead of just a few cases, the control variables that may affect construction costs and CWM performance are considered 'controlled'.

3.3 Testing H_1

For the purposes of comparing the construction cost of regular projects with that of BEAM-driven projects, unit construction cost (UCC) is used. The UCC is calculated on the cost spent on each unit of GFA built (e.g. ft^2 or m^2). The UCC of a building i is defined as: $UCC_i = Cost_i/GFA_i$, where i is the building project number, $Cost_i$ is the construction contract sum of building i, and GFA_i is the gross floor area of the building i. The contract sum accounts for only the cost in the construction phase. The hypothesis is tested by comparing the UCCs between the group of BEAM-driven buildings and the group of regular buildings.

3.4 Testing H_2

Waste generation rate (WGR) has been widely used as a proxy of waste minimization performance. A WGR of a building can be calculated by dividing the waste quantity (volume by m^3 or weight by tonnes) by the amount of construction materials, gross floor area (GFA) (Formoso et al., 2002), or construction contract sum (Lu et al., 2016a); it reflects the wastage rate of producing every unit of construction work. GFA is accepted as being the best description of the physical profile of a green building and as a denominator to understand *WGR* (e.g. worth of construction work). Following this argument, the *WGR* of building *i* is defined as: $WGR_i = WG_i/GFA_i$ where *i* is the building project number, WG_i is the total waste generation of building *i*, and GFA_i is the gross floor area of building *i*. This hypothesis is tested by comparing the WGRs between the group of BEAM-driven buildings and the group of regular buildings.

4. DATA DESCRIPTION

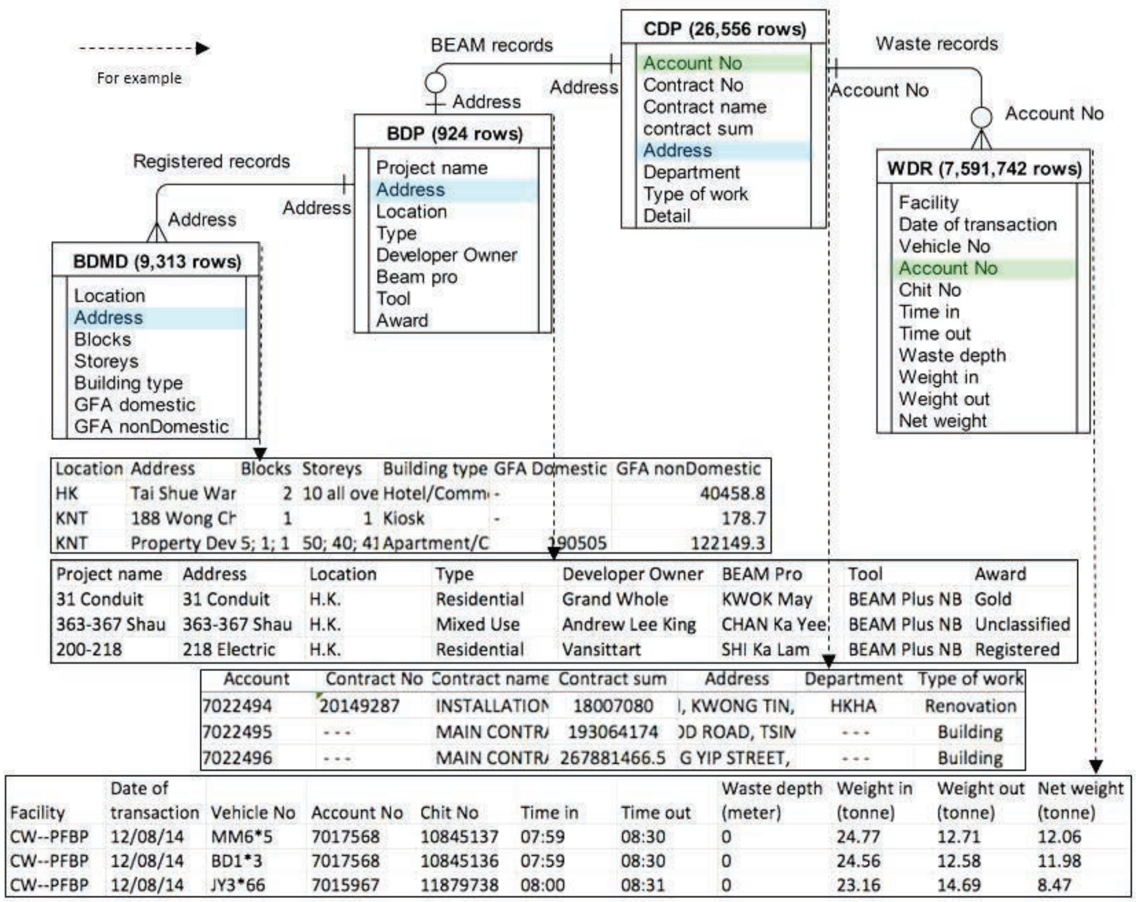
4.1 Data sources

A Construction Waste Disposal Charging Scheme has been enacted in Hong Kong since 2006. It mandates that main contractors pay for the disposal of construction waste in government facilities, such as landfills or public fills. Contractors are mandated to dispose of their waste at the facilities, if not otherwise properly reused or recycled. The HKEPD records every truck of construction waste received at these facilities. This leads to around 3,300 incoming records every day. The waste is generated from various projects, with their profiles such as site address, client, and project type being recorded. This study uses all the waste disposal data from 1 January 2011 to 31 December 2016 in Hong Kong, totalling 7,591,742 records generated from all 26,566 C&D works (see Figure 1). All the data were well structured in various databases, upon which the dependent variable WGR_i was calculated. This study has also sourced the data from the 924 buildings (as of 20 March 2017) that have been certified or registered for certification by BEAM Plus. The information of the 924 buildings, including project names, site addresses, level of green building label, and their waste generation records was extracted and forms the big data set as shown in Figure 1. In addition, for linking the GFA of the studied buildings, the information of 9,313 buildings has been extracted from the *Monthly Digest* of Hong Kong Buildings Department from 2005 to 2016 for bridging the contract sum and GFA of the same buildings according to their site addresses. The 924 BEAM-driven projects have been removed from the 9,313 buildings to generate a group of regular projects with the largest accuracy. Section 5 elaborates on the links between these databases. In order to simplify the names of the databases, Table 1 shows abbreviated names and recorded numbers.

4.2 Sample selection

The data finally employed for analysis accounts for a small part of the big datasets. Data mining is used for the purpose of extracting useful information from a large volume of data. For calculating the UCC, a link between the contract sum and GFA needs to be established. For calculating the WGR, a link between the waste generation amount and GFA needs to be established. The contract sum is in CDP, GFA is in BDMD, waste generation amount is in WDR (referring to Table 1). To link the waste amount with GFA, the only bridge is the construction site address. Therefore, the construction site addresses can be used as a bridge linking BDMD, CDP, and

FIGURE 1. Structure of the big data and links between databases.



BDP to select the samples for BEAM-driven projects and regular projects according to the following criteria:

a. The same address should exist in BDP, BDMD and CDP for extracting samples of BEAM-driven projects.
b. The same address should exist in both BDMD and CDP, but not in BDP, for extracting samples of regular projects.

TABLE 1. Descriptions of big data.

Abbreviation	Database	Number
CDP	Construction and demolition projects	26,556
BDP	Buildings that have applied BEAM Plus	924
BDMD	Buildings Department Monthly Digest	9,313
WDR	Waste disposal records	7,591,742

There is only construction site address in common between the above three databases. Their longitude and latitude are geocoded by engaging the cooperation of the Google Geocoding Service. The links are then established by automatic matching, manually checking the errors, and matching any addresses without an exact longitude and latitude. Although the matching is not ideal, a considerable sample size is available for data analysis. In addition, although there is no address in WDR there is an account number that can be used to represent a site address, which can link WDR and CDP to calculate the waste generation period and the amount for each project. This study regulates that the period for selected samples should fall in the range from 1 February 2011 to 30 November 2016. This is to largely increase the possibility that all the projects selected were finished during the period of 2011 to 2016. If a project still generates waste in either one of those two months, it probably had started before 2011 or had not yet ended in 2016. To guarantee the data completeness of selected samples, this study stipulates that the projects should have no waste generation in either January 2011, the beginning time of the collected waste records, or December 2016, the end date. Since during the linking process there were a large volume of projects that failed to establish links, the samples for carrying out the comparison are comparatively smaller than the original datasets; they are however still very considerable. After linking and filtering according to a 90% confidence level, the profile of the available construction costs for comparison is displayed in Table 2, and that of the available WGR is in Table 3.

5. DATA ANALYSIS

This section tests the hypotheses using the collected big data with the proper data analysis methods. The data analysis is divided into two individual parts to test H_1 and H_2, respectively. Section 5.1 tests H_1 by comparing the UCC between regular and BEAM-driven projects, and Section 5.2 tests H_2 by comparing their respective CWM performance.

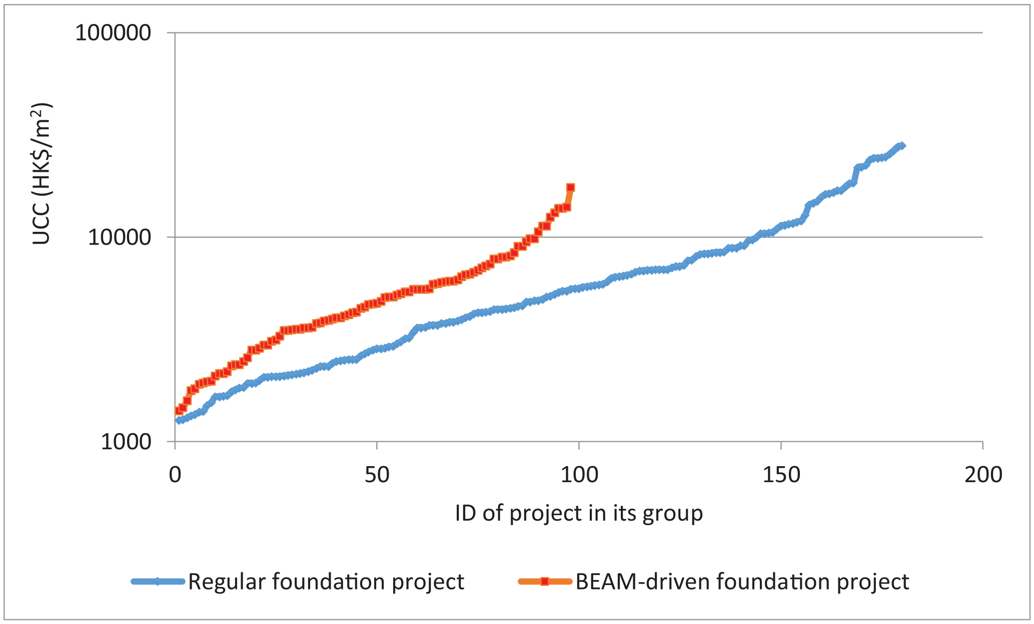
TABLE 2. Sample sizes for UCC comparisons between regular and BEAM-driven construction works.

Construction stage	Regular	BEAM-driven
Foundation	180	98
Building	197	98
Total	377	196

TABLE 3. Sample sizes for WGR comparisons between regular and BEAM-driven construction works.

Construction stage	Regular	BEAM-driven
Foundation	107	96
Building	153	94
Total	260	190

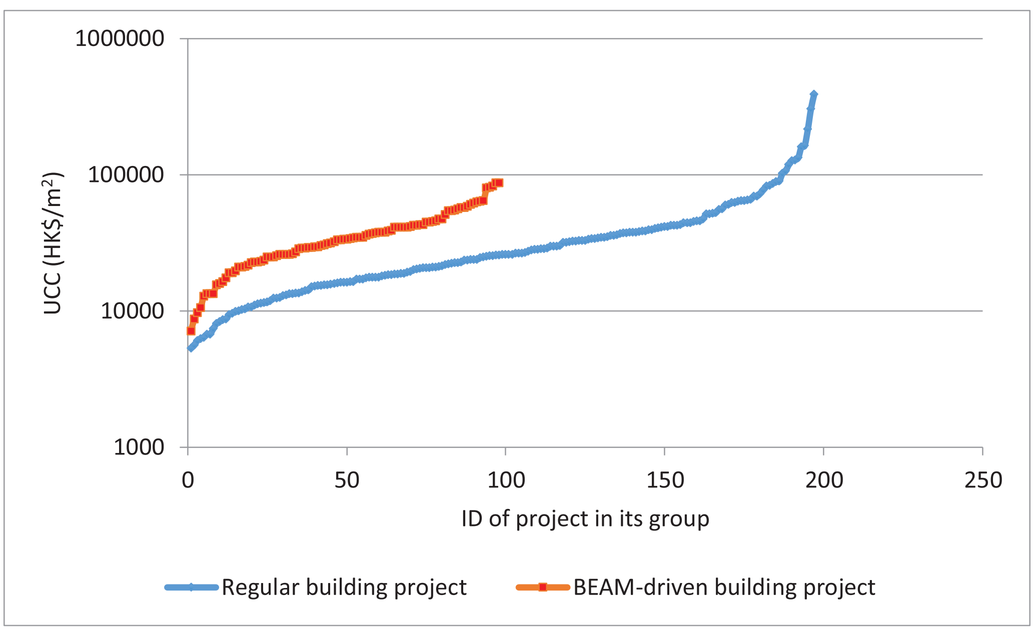
FIGURE 2. Comparison of the UCCs between regular and BEAM-driven foundation projects.



5.1 Comparing the UCC between regular and GBRS-driven projects

Using the formula described in Section 3.3, the UCC for foundation and building projects are calculated and plotted in Figures 2 and 3, respectively. Figures 2 and 3 display the results of the UCCs after a complicated process of data cleansing, sample selection, and calculation. It can be seen from Figures 2 and 3 that the UCCs of BEAM-driven buildings appear generally larger

FIGURE 3. Comparison of the UCCs between regular and BEAM-driven building projects.



than those of the regular buildings, while the maximum of the latter is higher than the former. Whether the UCC of BEAM-driven buildings are higher is examined statistically.

The distributions of the UCCs for the four groups are plotted in Figure 4, and since all of the groups tend to follow a positively skewed distribution, the median UCCs instead of the mean UCCs are adopted as a better representative of each group of regular and BEAM-driven green building projects. The means and medians, along with the difference of the median UCCs between BEAM-driven and regular buildings are shown in Table 4. The result of the calculated UCCs is well in line with the reported values from other sources. For example, Rider Levett Bucknall (RLB), a local surveying firm publishing building costs regularly in Hong Kong, estimates the average UCC as between HK$2,248 to HK$3,456 per square foot for a mid-rise apartment building providing homes of 650 to 750 square feet (Chow, 2017), and the average UCC is between 24,197 to 37,200 HK$/m^2. The results of this study indicate that the total UCC for a building is 25,865.46 HK$/m^2 for regular projects and 33,508.44 HK$/m^2 for BEAM-driven projects.

The significance of the difference is statistically examined using Mood's median test approach, which is a nonparametric test that is used to test the equality of medians from two or more populations. The null hypothesis is that there is no significant difference of the UCCs between regular and BEAM-driven buildings. The alternative hypothesis is that there is a significant difference in the UCC between regular and BEAM-driven buildings. When a p-value is less than 0.05, the null-hypothesis should be rejected, and the difference between the medians can be regarded as significant (Peng et al., 2018). The p-values as displayed in Table 4 indicate that a statistically significant difference exists in the UCC of BEAM-driven and regular buildings, at both foundation and building stages. It was also found that the BEAM Plus accreditation

FIGURE 4. Histograms of the UCCs of regular and BEAM-driven buildings at foundation and building stages.

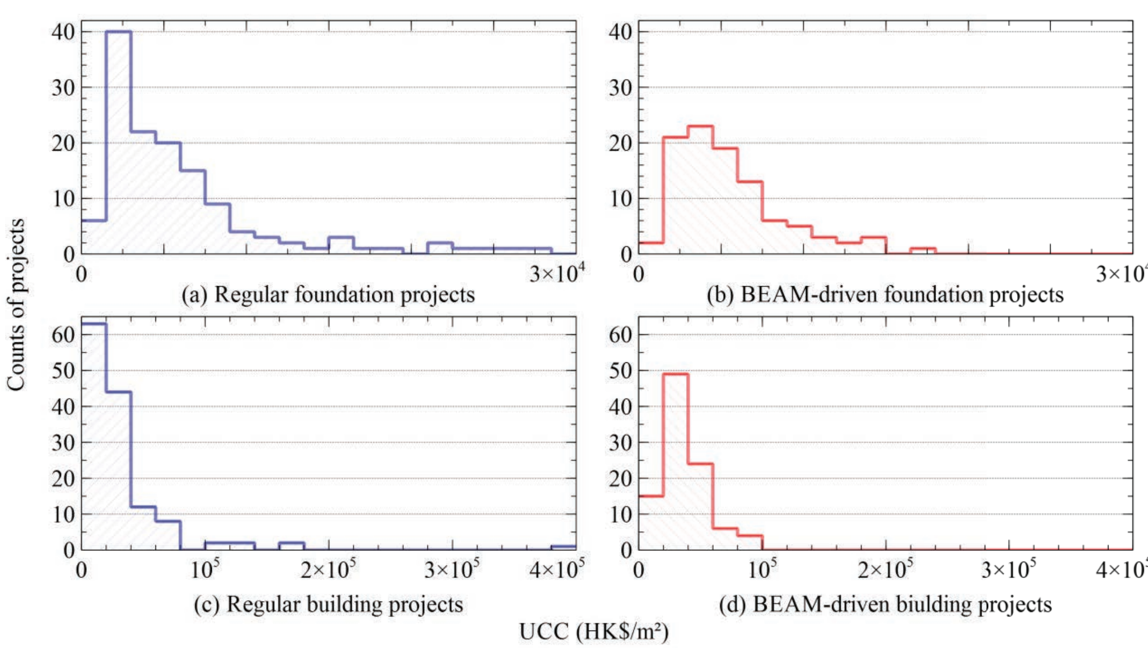


TABLE 4. Mood's median test for comparing the UCC between regular and BEAM-driven buildings.

Construction stage	Regular (HK$/m^2)		BEAM-driven (HK$/m^2)		Median difference		p-value	Difference significance
	Mean	Median	Mean	Median	HK$/m^2	%		
Foundation	7,050.56	4,946.77	5,484.00	4,744.60	–202.17	–4.09	0.0007	Yes
Building	37,481.65	25,865.46	36,130.35	33,508.44	7,642.98	29.05	0.0031	Yes

reduces the cost of foundation works by approximately 4.09%, while increasing the cost of building works by about 29.55%.

This study assumes the median foundation cost of BEAM-driven projects is F_1, and that of regular projects is F_2. The median building cost of BEAM-driven projects is denoted by B_1, and that of regular projects by B_2. As F_1 and B_1 both represent the median cost level for BEAM-driven projects in Hong Kong, the foundation and building works for BEAM-driven projects at the median level can be regarded as different stages of the same building, which is at the median cost level in Hong Kong, and the same applies to the regular projects. Foundation and building are the two main stages for a building. Therefore, this study sums up F_1 and B_1, and F_2 and B_2 respectively to represent the total median UCC for BEAM-driven and regular projects. The increased percentage of UCC can be calculated as: $(F_1 + B_1)/(F_2 + B_2) - 1$. The number is 24.15%, which means BEAM-driven buildings generally cost 24% more than regular buildings. Therefore, H_1 is supported by the statistical results. An extra cost for pursuing a GBRS certificate is needed.

5.2 Comparing CWM performance between regular and GBRS-driven buildings

According to the methodology presented in Section 3.4, the WGRs for foundation and building projects are calculated and plotted in the order of significance in Figures 5 and 6 to demonstrate the calculated results of WGRs of the selected samples. Relying on Figures 5 and 6 alone, it is difficult to tell whether BEAM-driven projects have a greater WGR than the regular projects, as the tendencies of their respective lines look similar. The differences of cost for both foundation and building projects are statistically examined.

Before conducting the statistical comparisons, the distribution of the WGRs for the four groups are plotted in Figure 7. Figure 7 shows all the groups tending to follow a positively skewed distribution, and the median WGR rather than the mean WGR is shown to be a better representative of the waste management performance for each type of BEAM-driven and regular construction work (Lu et al., 2015; Lu et al., 2016a). The calculated means and medians of WGR are listed in Table 5. If a BEAM-driven building has lower WGR than a regular one, this building can be regarded as having achieved a better CWM performance, probably driven by attempts to gain BEAM Plus credits.

The null hypothesis of Mood's median test is that there is no significant difference in the WGRs between regular and BEAM-driven buildings. The alternative hypothesis is that there is a significant difference in the WGRs between regular and BEAM-driven buildings. The calculated differences between medians of WGRs of BEAM-driven and regular buildings for both

FIGURE 5. Comparison of the WGRs between regular and BEAM-driven foundation projects.

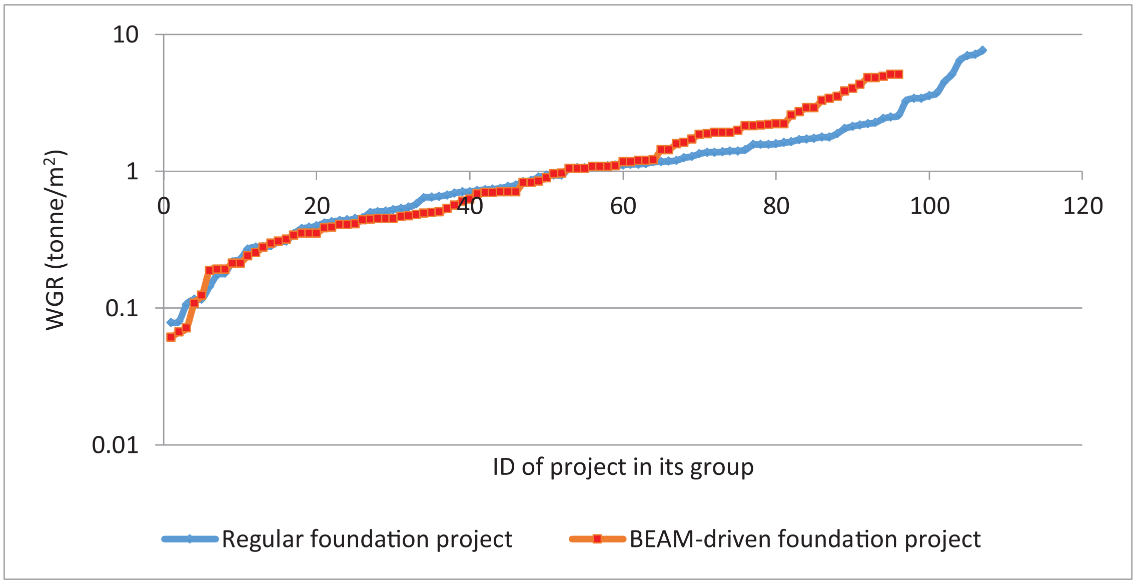
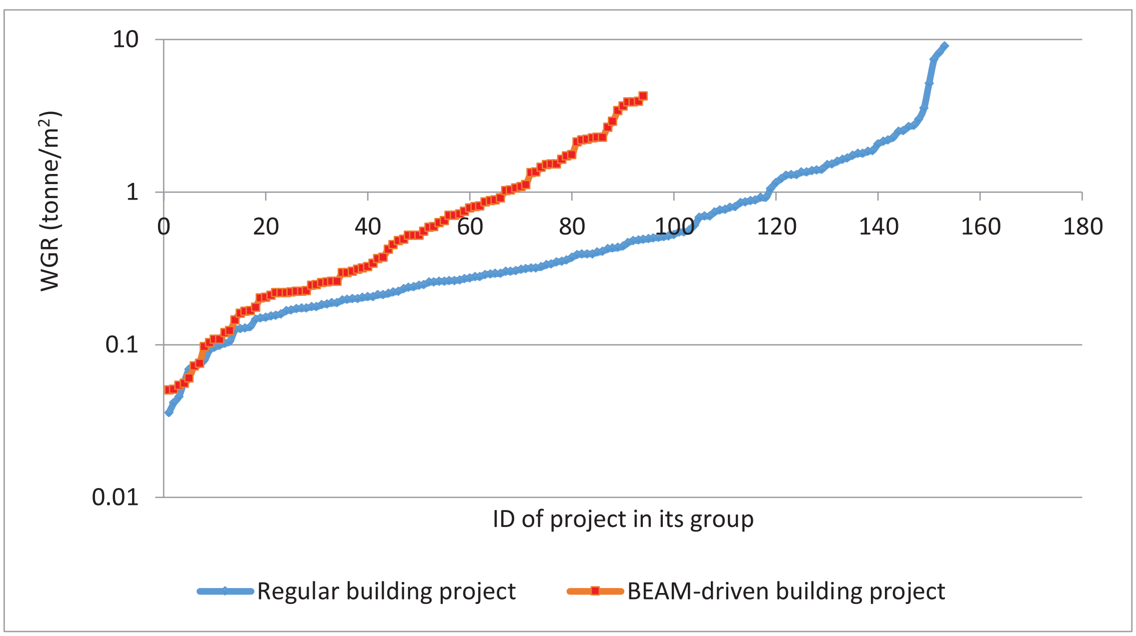


FIGURE 6. Comparison of the WGRs between regular and BEAM-driven building projects.



construction types are listed in Table 5. The results (p-value > 0.05, and WGR significance = No) show that the BEAM Plus has non-significant effects on CWM in both foundation and building works. H_2 is not supported. The results indicate that BEAM Plus has not yet obviously differentiated green buildings from regular buildings in its CWM performance. The large number of samples at 196 green buildings fail to demonstrate the advantage of CWM performance when

FIGURE 7. Histograms of the *WGR*s of regular and BEAM-driven projects at the foundation and building stages.

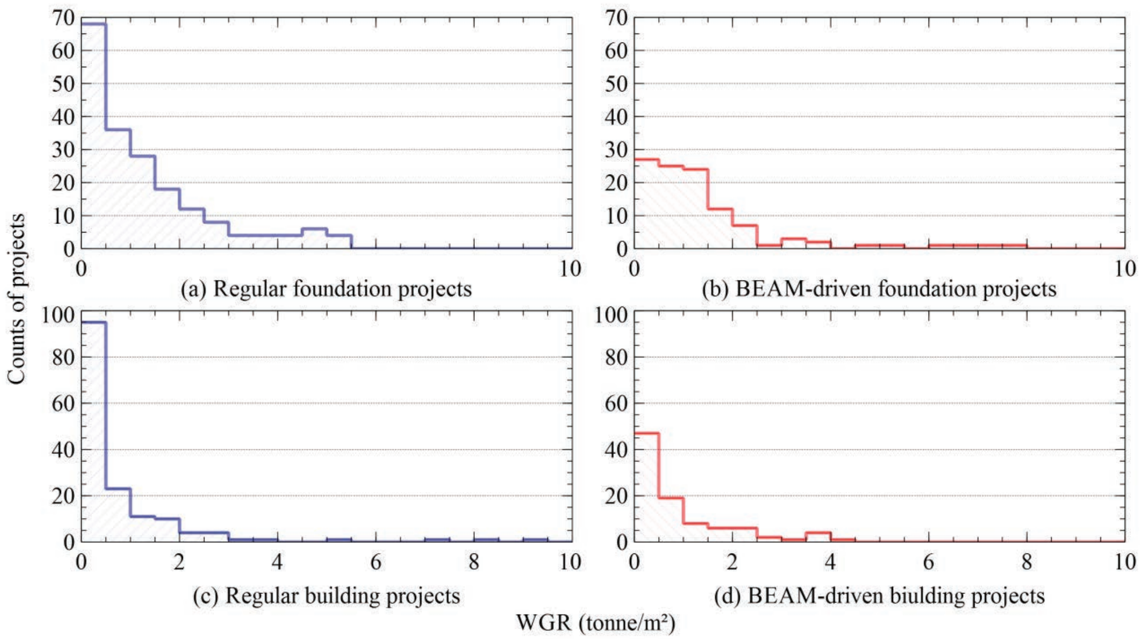


TABLE 5. Mood's median test for comparing the WGRs between regular buildings and green buildings.

Construction stage	Regular (ton/m^2)		BEAM-driven (ton/m^2)		Median difference (ton/m^2)	*p*-value	Difference significance
	Mean	Median	Mean	Median			
Foundation	1.39	1.06	1.33	0.84	–0.22	0.1955	No
Building	0.82	0.35	0.90	0.50	0.15	0.2406	No

applying BEAM Plus. It would therefore appear that this GBRS could not effectively incentivize the CWM aspect as part of its general aim of pursuing sustainable development.

6. DISCUSSION

This study estimated an increase of 24.15% in the cost of developing green buildings. As stated in H_1, green buildings cost more than regular ones because developers need to add the cost of the effort to achieve the green scopes in the GBRS. Compared with 1–11% extra cost driven by LEED in the US (Miller, 2008) and 3–5% or more driven by the Green Star in Australia (Langdon, 2007), the extra cost of green building driven by the BEAM Plus in Hong Kong seems to be higher. This is partly due to the additional cost in Hong Kong's highly compact economy of balancing the imports of green materials and prefabricated elements for satisfying the green scopes. This study discovered that the foundation stage of green buildings cost a little less but the building stage costs much more than regular building. This is in part due to the achievable items in GBRSs that are far more relevant to the building stage (i.e. superstructure) rather than the foundation stage. Most items are for the superstructure, which constitutes a majority of attainable credits in the most important scopes, such as energy saving and water conservation, where additional cost is needed for material procurement and delivery, and installation. As these aspects seldom relate to costs at the foundation stage, applying for green building certification costs far more at the building stage than at the foundation stage. However, the important consideration for developers to remember when they are considering whether or not to apply for green building certification in Hong Kong is that the overall construction costs involved are approximately 24% higher than for construction of a regular building.

The BEAM Plus has a negligible influence on CWM performance according to the statistically significant difference in the WGRs between regular projects and BEAM-driven projects, either at the foundation stage or building stage. This might due to the low total weighting of CWM-related items (excluding those for demolition stage) where the credit allocation for waste reduction at the foundation and building stages is only 2.18% under BEAM Plus. It is surprising to find that the foundation stage generated a far larger amount of construction waste sent to disposal facilities than the building works. This might be due to the fact that foundation work includes not only piling but also excavation, which generates a large amount of inert waste such as soil and rock. The large amount of foundation waste disposed of at facilities is due to the difficulty of directly reusing inert waste at the construction site.

From the findings of this research, it can be concluded that green building accreditation using BEAM Plus generally increases the cost of construction by approximately 24%, while having a negligible effect on CWM. The increased construction cost of green buildings will not be offset by CWM as long as its corresponding setting in the BEAM Plus continues without incentivizing a behavioural change. In order to improve CWM performance through promoting GBRSs, this study suggests isolating foundation waste minimization as an additional item with more attainable bonuses to encourage innovative solutions for minimizing construction waste. As there is great potential for the reuse of foundation waste, it is suggested that a platform for the market be developed where other construction sites can share waste materials. By doing so, contractors can save waste-disposal-related fees, including waste transportation fees, facility disposal fees, labour fees, and the value of the materials. This will also contribute to energy saving and carbon emission reduction in the material flow (Shuai et al., 2018). As such, the extra construction costs for constructing green buildings can be recouped from these costs saving and sustainable features harnessed from CWM improvements.

7. CONCLUSIONS

This study examined the extra construction costs and benefits of green buildings, focusing on CWM performance specifically. It did so by using the construction waste management and building data covering Hong Kong projects in totality, instead of data samples collected from traditional approaches, such as interviews and questionnaires. The results show that buildings applying for BEAM Plus certification—the dominant GBRS in Hong Kong—generally cost approximately 24% more than regular buildings. Constructing GBRS-driven buildings involves extra construction costs because developers need to pay extra for the green features. Surprisingly, BEAM Plus is shown to have only a negligible effect on CWM. The statistically insignificant effect of green buildings on CWM can be explained by the difficulties of conducting CWM, and the lack of incentives for doing so at both the foundation and building stages.

This study makes two suggestions for improving the effects of GBRSs on CWM. Firstly, there should be a finer approach for GBRSs to isolate foundation waste minimization as an item allocated with more attainable credits and bonuses for innovation. Secondly, GBRSs should encourage contractors to share waste materials for reuse rather than sending them straight to government disposal facilities.

Finally, there are limitations of this study and suggestions for further related research can be offered. Since this study did not specifically consider sustainability benefits such as water and energy savings by integrating them with construction costs, it is recommended that future research investigate a full coverage of sustainability performance in order to provide a more comprehensive cost benefit analysis, and since the GBRS was examined with empirical data exclusively from Hong Kong, future studies could examine green buildings' CWM benefits in other jurisdictions using a similar full-scale empirical data approach.

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