Evaluating the effects of green building on construction waste management: A comparative study of three green building rating systems

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Abstract

The impacts of buildings on our life, business, and natural environment have fueled a global trend in the building industry to "go green". This has helped proliferate various green building rating systems (GBRSs) around the world. While previous studies have examined the effects of these systems on such aspects as resources consumption, indoor air quality and property value, little research, if any, has examined their effects on construction waste management (CWM). This study aims to evaluate the effects of GBRSs on CWM, and to understand the causes behind the effects thereof ascertained. Three GBRSs, including the U.S.-developed Leadership in Energy and Environmental Design (LEED), Mainland China's GB Evaluation Label (GBEL) and Hong Kong's Building Environmental Assessment Method (BEAM Plus) are selected for comparative study. A combination of desktop archive analysis and semi-structured interviews formed the study's mixed method approach. Surprisingly, the study reveals that the three GBRSs do not greatly promote superior CWM performance despite their respective CWM targeted credits. Possible causes, as informed by the interviewees, include the design of rating systems themselves, developers' biases, and lack of incentives to improve CWM. Legal and economic incentives are more decisive drivers of responsible CWM. This

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paper also provides demonstrable qualitative evidence for legislators and associated bodies to achieve continued improvement in CWM via GBRSs.

Keywords: Green building; Green building rating system; Construction waste management; LEED; GBEL; BEAM Plus

1. Introduction

Building is a widely alleged chief culprit of environmental degradation by intensely consuming non-renewable resources and causing land depletion and deterioration, solid waste generation, dust and gas emissions, and noise pollution [1,2]. Consequently, how to undertake 'green' building has received widespread attention from both researchers and practitioners over the past decades [3,4]. The term 'green building (GB)' here can refer to the practice of creating and using healthier and more resource-efficient models of construction, renovation, operation, maintenance and demolition [5]. It could be a noun to represent the physical building, or a gerund to represent the sustainable construction process [6].

Amidst the global trend of "going green", many construction-related institutions have pushed GB to the top of their agenda. An array of governments, professional bodies, and independent organizations have issued green building rating systems (GBRSs) in past decades to define GB standards and award certifications. A source from Vierra [7] estimated that there are approximately 600 such GBRSs globally. The evaluation criteria for most major systems largely fall under eight categories: project management, site, energy, water, materials, emissions and storage of hazardous materials, and indoor environment [8,9]. GB projects normally incur higher upfront costs than ordinary buildings due to the applications of more sustainable materials or building services systems that should be paid off through improved environment performance or property value [6]. A myriad of research studies has thus been conducted to evaluate the effects of GB on carbon emission reduction (e.g., [10]), energy saving (e.g., [11]), occupant comfort (e.g.,[12]), and property market price (e.g., [13]). Yet, only a small number of studies examined the effects of GB on construction waste management (CWM), regardless of the fact that CWM is also an important agenda of "going green".

Construction waste is the solid waste that arises from construction, renovation and demolition activities [14,15]. Huge amounts of construction waste are generated due to mounting construction activity tied to urbanization and urban renewal [16]. Conventional construction waste disposal methods include landfill and incineration, which not only rapidly consume invaluable land resources, but also give rise to environmental degradation [17]. Statistics from various economies (e.g., Japan, Hong Kong) show that construction as a single sector consistently contributes 20-25% of the municipal solid waste landfilled. How to tackle the problems arising from construction waste generation has thus become an acute issue to be addressed by various grand initiatives including the global green building movement. CWM is an indispensable part of various GBRSs. Researchers (e.g., [18,19]) discovered that construction waste related credits, normally under the category of "Materials", account for 8-12% of all the attainable credits in these systems. However, these studies are mainly constrained in comparing the GBRSs by looking into the systems' structure and credit design. Their real effects on CWM must be evaluated by using empirical evidence.

Lu et al. [6] conducted one of the first empirical studies to examine the effects of GB on CWM performance by triangulating the 'big data' with 'thick data', which means big quantitative data and small but in-depth qualitative data, respectively. They discovered that the Building Environmental Assessment Method (BEAM Plus), the dominant GBRS in Hong Kong, leads to “no statistically significant waste reduction for foundation or building works”. However, the study was confined in Hong Kong. When the authors of this paper extended their search to other GB projects in the U.S. and Mainland China rated by the U.S.-developed Leadership in Energy and Environmental Design (LEED) and Mainland China’s GB Evaluation Label (GBEL), it is interesting to notice that the GB projects consistently scored low in “Material” category, inducing that the designated goal of better CWM via GBRSs has largely unattained. This motivated the authors to ascertain the relationships between GB and CWM, and explore the potential causes behind.

This study aims to empirically evaluate the effects of GB on CWM and to understand the causes of the effects by extending the scope of this line of inquiry to a wider context. It has three specific research objectives:

- To ascertain the effects of GB rating systems on CWM;
- To uncover empirical evidence explaining such effects via extensive and in-depth semi-structured interviews; and
- To formulate a series of measures to improve CWM performance in GB projects based on the empirical evidence.

It does so by conducting a comparative study of the rating systems LEED, GBEL and BEAM Plus by adopting a mixed method approach to triangulate desktop archive empirical analyses with a series of semi-structured interviews. The research deliverables of this paper are of benefit to both researchers and practitioners in the GB industry. It also provides an important reference for those GB councilors who formulate GBRSs and continuously improve them.

2. Literature Review

2.1 The green building movement and rating systems

The concept of GB emerged in the 1960s from a growing consciousness of sustainable development [20]. It offers a strategy for minimizing the environmental impact of buildings, as well as enhancing human well-being, community, environmental health, and whole-life costs [21,22]. GB is a holistic practice for achieving sustainability throughout a project's life cycle [23]. A recent analysis by Dodge Data & Analytics predicts that the number of GB projects will double every three years [24]. However, GB implementation varies widely from one country to another depending on local triggers, obstacles, and green movement phases [25-27].

GBRSs are tools for evaluating a building's performance, including its environmental impacts, in accordance with a specified series of criteria that usually cover energy performance, site selection, water efficiency, indoor air quality, and materials utilization [8,9]. CWM principles normally fall under the 'material' aspect. The evaluation result translates into an overall standardized ranking and, based on the total score, a GB certification label is awarded [3]. National and regional governments have adopted various incentive policies offering economic returns for GB projects. For example, Mainland China's regional governments provide subsidies based on the level of GB certification a project has been awarded and its gross floor area (GFA). In Hong Kong, certified BEAM Plus projects have received a capped 10% of GFA concessions since 2011.

2.2 Construction waste management

Construction waste, sometimes termed construction and demolition (C&D) waste, refers to surplus and damaged materials resulting from building activities including new construction, renovations, and demolition [14,15]. The European Waste Catalogue classifies construction waste into eight categories including concrete, bricks, tiles and ceramics, wood, glass and plastic [28]. Construction waste is also classified as either inert or non-inert depending on whether or not it has stable chemical properties [29]. Inert materials, such as soil, earth, slurry, rocks and broken concrete, account for the vast majority of all construction waste [30]. The non-inert waste, which includes bamboo, paper, and timber, cannot be reused and/or recycled and is normally landfilled.

While the construction industry contributes significantly to economic development, mounting construction waste has become a serious global issue. In the U.S., an estimated total 548 million tons of construction waste was produced in 2015 [31]. The UK generated 55 million tons of non-hazardous construction waste in 2014 according to the Department for Environment, Food and Rural Affairs [32]. In Hong Kong, the statistics issued by the Environmental Protection Department (EPD) [29] put production of C&D waste at 1.62 million tons in 2016, accounting for about 29% of Hong Kong's total solid waste landfilled. Landfilling not only causes environmental degradation due to the production of CO_2, methane and leachate from anaerobic degradation of the materials, but also rapidly exhausts invaluable landfill capacity [33,34].

The two previous sections attest to how GB and CWM have been investigated separately. Some recent studies (e.g., [6,35]) discuss the effects of Hong Kong's BEAM Plus on CWM performance. Lu et al.[6] find that BEAM Plus significantly influences CWM performance in demolition projects, however, it only marginally reduced the waste generated from foundation and building works. Chen et al. [35] point out that BEAM Plus has a negligible effect on CWM. Nevertheless, these studies are mainly confined in Hong Kong. Wu et al. [36] compare CWM criteria in five internationally representative ratings systems, whereas the influence of GBRS on CWM performance in real practice using empirical data are not studied. Other than these, studies exploring CWM performance within the context of GBRS are limited.

3. Research methods

The research described here epitomizes a typical comparative study, which refers to the act of comparing two or more things with a view to discovering something related to the things compared. Comparative study is one of the most efficient methods for explicating or utilizing tacit knowledge to understand a matter in question. There are different taxonomies of comparative study methodologies. Yet, there is no methodology peculiar to comparative research [37]. A commonly adopted taxonomy is descriptive vs. normative comparative study. The aim of a normative comparison is to find out the best amongst the alternatives that are studied, while a descriptive comparison could be about different things, or the same thing under different circumstances, or their combination. A key issue in conducting comparative empirical research is to ensure equivalence [38]. The "thing" in this study could be GBRSs, GB projects, or GBRSs in different circumstances. By carefully considering the research aim, the "equivalence" issue, and the data availability, this study focuses on their GBRSs (e.g., LEED, GBEL and BEAM Plus) operating in different economies (e.g., The U.S., Mainland China, and Hong Kong). The unit of analysis is "GBRS in an economy" by considering the connection of a GBRS and its contextual circumstances.

The comparative study adopts a mixed method approach with two interconnected parts. First, a series of desktop archive analyses of three GBRSs in the contexts of the U.S., Mainland China, and Hong Kong are undertaken to ascertain their correlation with CWM. Normally, GB councils only release an overall rating of a GB; rarely the detailed scores of different aspects, in particular CWM, of a GB can be obtained. This part of research is benefited from the availability of good secondary data on 88 GB projects in the three economies. The empirical data, even with simple analytics, is sufficient for inducing the correlation between GB and CWM. Second, a series of semi-structured interviews are conducted with GB experts in the three contexts to collect the first-hand qualitative data, which is consider the optimal way to understand the causes behind the ascertained correlation. The triangulations of the data collected from the two parts of studies will allow the insights towards the effects of GBRSs on CWM to surface.

3.1 Archive analyses

The first research objective is to ascertain how GB projects affect CWM performance. To reiterate, the unit of analysis is GBRSs in different contexts. The authors focus on LEED, GBEL, and BEAM Plus for coverage of an international, national, and local context, respectively. LEED generally works concurrently with regional rating tools and awards certificate levels based on cumulative points achieved without weighting a credit based on its category [39]. This study uses LEED v2009 New Construction as the number of projects certified under the most recent version, LEED v4, remains limited at the time of this study. The Ministry of Housing and Urban-Rural Development of the People's Republic of China (MOHURD) launched the first version of GBEL in 2006. GBEL consists of two assessment standards for residential and public buildings, as well as two phased rating certificates: GB Design Label (GBEL-DL) and Operation Label (GBEL-OL). Certified by the Hong Kong GB Council (HKGBC) and assessed by the BEAM Society Limited, BEAM Plus offers an independent evaluation of building sustainability performance in Hong Kong and beyond. This study analyzes the latest version, BEAM Plus New Buildings (V1.2).

To start, the authors analyzed where the CWM-related credits normally reside. It was found that these credits mainly fall under the category of 'Materials'. For example, LEED awards a CWM prerequisite credit, essentially requiring that a project devise a CWM plan before opening a full LEED application. In GBEL, the credits relating to CWM are allocated in two sections under the labeling systems ‘Material saving & material resource utilization’ and ‘Construction management’. BEAM Plus places the pertinent CWM credits under ‘Materials aspects’.

Then, the authors identified the CWM-associated credits by examining their credit criteria item by item. This required much more effort than the first step, as many criteria are implicitly embedded in the system and depend on proper stakeholder interpretation. An inter-rater approach was adopted to calculate a tentative list, which was further verified by the interviewees in the next stage. The authors also compared the findings with previous studies conducted by Wu and Low [8] and Wu et al. [36].

Next, the authors collected 88 certified GB projects by different GBRSs in three economies including the U.S., Mainland China, and Hong Kong. As shown later in the Analysis section, data of the 88 projects is consistent and particularly good. By connected with the CWM-related credit analyses, it is good enough for inducing a conclusion to be further substantiated by using the qualitative studies as described below.

3.2 Semi-structured interviews

While the above archive studies may help ascertain the association between GB and CWM, their causes cannot be understood without probing into the industry’s practices. Hence, a series of semi-structured interviews were conducted to garner qualitative data from GBRS and CWM practitioners. Professional and personal contacts specializing in GB projects were sourced and a combination of in-person and Skype interviews informally conducted. Topics include CWM obstacles in the context of GB, which credits apply to CWM either explicitly or implicitly in each rating system, and other potentially more important institutions and regulations affecting

CWM. The informal interview results were used to formulate more targeted interview questions. A new round of interviews was conducted with 22 GB practitioners, including GB council members, experts, developers, consultants, and contractors based in the U.S., Mainland China, and Hong Kong (see Table 1) that have participated in LEED-, GBEL-, or BEAM Plus-certified projects at a high level.

<<Insert Table 1 here>>

Initial interview questions were open-ended to elicit the interviewee's overall views on the relevant GBRS. Questions were then more CWM-specific, e.g.:

- What is your understanding of the evolution of CWM's structure and importance or waste reduction credits within the system from its inaugural to current version?
- In your opinion, at what stage in the project life cycle does CWM occur in GB projects?
- Does CWM feature in any credits other than those in which it is explicitly mentioned?
- What is best practice for optimizing CWM credits?

Broader questions were then asked to tease out the CWM position in relation to other credits, e.g., in your opinion:

- Which credits are most difficult to obtain?
- Is efficient use of materials a construction waste category?
- Do you have any novel approaches to disposing of construction waste?
- With regards to documentation, how do you undertake data collection and recoding in accordance with GB evaluation?

The interviewees were provided with a list of credits from the GBRS with which they are familiar so that they did not need to rely on memory to compare the categories and credits within their respective GBRS. The interviews were conducted between July and December 2018. Each lasted around one to three hours, though the majority took about one hour. Some were audio-recorded, while detailed notes were taken instead if the interviewee was uncomfortable with audio-recording.

4. Results and analyses

4.1 Comparisons of the credits allocated to CWM

The three GBRSs share a similar crediting mechanism in assessing building performance and awarding green labels. They generally divide their credits into ‘land use’, ’water’, ‘materials’, ‘energy’, and ‘indoor environmental quality’, and some bonus credits. All demand one or two prerequisite credits for each category, while additional optional credits contribute to the total score and thus determine the awarded GB ranking. However, each GBRS assigns different weights to their performance categories, which reflect regional priorities and intentions [9]. Details are exhibited in Tables 2, 3, and 4.

<<Insert Table 2 here>>

<<Insert Table 3 here>>

<<Insert Table 4 here>>

The comparisons show that the LEED, BEAM Plus, and both phased rating certificates of GBEL all feature a materials-focused category comprising the credits related to CWM. However, they do so in dissimilar ways and with different emphases. For instance, the three systems calculate the waste recycling rate differently. The LEED and BEAM Plus set the percentage of total construction waste to be recycled or salvaged as the threshold, 50% for LEED and 30% for BEAM Plus, while GBEL calculates the weight of solid construction waste per 10,000 m^2 GFA. Moreover, GBEL and BEAM Plus encourage the use of prefabrication as an optional criterion to minimize material inefficiencies. LEED, however, appears to lack this specific requirement. As reflected in the material saving and material resource utilization category, avoiding unnecessary construction waste seems to be the main goal of GBEL as opposed to recycling.

From Table 2, it can be seen that 14 out of 110 credits are allocated to materials and resources. Meanwhile, of the 14 credits, 11 are attainable through CWM. Therefore, a considerable portion of materials and resources credits are related to CWM. Similar results can be found in other GBRSs. For example, 100 out of 510 credits are allocated to materials in GBEL-DL, and 84 of the 100 credits are attainable through CWM; 200 out of 710 credits are allocated to material and construction management in GBEL-OL, and 118 out of the 200 can be achieved through CWM (see Table 3); in BEAM Plus, materials aspects are allocated with 22+1B credits, amongst which 17+1B are attainable through CWM (see Table 4). A significant portion of credits are therefore attainable through CWM.

4.2 Low scores of 'materials' aspects in real-life GB projects

Tables 5, 6, and 7 show the data of 88 GB projects, including five performance categories: site, water, energy, materials and IEQ, which the authors collect from various sources. Table 5 depicts the credit distribution of 53 LEED-accredited projects from the U.S., Mainland China and Hong Kong. Across all the LEED-accredited projects, regardless of their locations, only about 40% of the total attainable credits in the materials and resources (MR) category are achieved, the lowest rate of any category by far. Coincidentally, it can be seen from Tables 6 and 7 that the eight GB projects awarded with Mainland China's GBEL and the 27 projects awarded with Hong Kong's BEAM Plus also earned relatively lower credits in the materials category compared with others.

<<Insert Table 5 here>>

<<Insert Table 6 here>>

<<Insert Table 7 here>>

From Section 4.1, it can be concluded that a significant portion of the credits are attainable through CWM. Meanwhile, the analyses in Section 4.2 so far indicate that the scores for ‘materials’ are consistently low in real life GB practices, suggesting that attained credits through CWM are low. One may argue the attained credits through CWM can still be high in percentage although the scores of overall ‘material’ aspects are low. The data collected from the LEED and GBEL-certified projects provided the detailed scores of under each category, allowing researchers to perceive how CWM is executed in real-life GB practices. A new column called CWM is added to Tables 5 and 6. It can be seen from the two tables that indeed CWM scored low in the 61 GB projects. The detailed scores of CWM in the BEAM Plus–certified projects are not available.

Drawing up the analyses elaborated in Sections 4.1 and 4.2, it can be concluded that real-life GB projects, regardless of their certified systems or locations, consistently scored low in ‘materials’ aspects, and in turn, CWM-related credits, suggesting a non-significant correlation between GB and CWM. It is sufficient to say that the three GBRSs, namely, LEED, GBEL, and BEAM Plus, did not achieve the designated goal of promoting superior CWM performance. It would be interesting to stakeholders, green building councilors in particular, to understand the reasons behind this unexpected phenomenon.

4.3 Semi-structured interviews

The main points obtained from the interviews are summarized in Table 8, and the primary causes of marginal GBRS effects on CWM are elaborated in the following subsections.

<<Insert Table 8 here>>

4.3.1 Low weighting and high cost to obtain CWM-related credits

The weighting applied to each performance category markedly impacts the scoring strategy in each GBRS. This is widely acknowledged by interviewees, especially the GB consultants. Although CWM concerns a large portion of materials-related credits, the weights given to the materials category are rather low; 12.7% in LEED (see Table 2), 18% in GBEL-DL, 14.5% in GBEL-OL (see Table 3), and 8% in BEAM Plus (see Table 4). Note that in LEED, there is no weighting, i.e., 1 credit equals 1 point earned toward the total score. Consequently, the MR credits equal 14 out of 110 possible credits, i.e., 12.7%. Whereas GBEL and BEAM Plus value some credits over others and so do not allow such equivalent percentages. They value material aspects credits below those from other categories, and thus the associated CWM credits as well. These different weightings show an obvious disregard for the 'material' category within BEAM Plus, and only a slight lesser importance among GBEL and LEED.

With regard to cost effectiveness, the majority of projects would earn more credits from categories other than 'materials' in BEAM Plus. One consultant in charge of BEAM Plus certification claimed:

> *We always give 'materials aspect' the lowest priority when we make a scoring plan in BEAM Plus. The credits under 'materials aspect' are normally regarded as the supplementary if the overall scores are not sufficient according to the target award ranking, e.g., platinum, or gold. If the project is aiming at silver certification or above, we would consider optional credits with respect to 'materials aspect'.*

This is exacerbated by soaring construction costs in different regions. One project engineer in charge of a GB project reflected:

> *Generally speaking, apart from the classification into inert, non-inert, and metallic materials, we won't pay additional effort on waste sorting on site to further reduce the waste, because the estimated expense on landfill charging has been already included in the tender. Moreover, compared with the considerable manpower cost caring on sorting, the current 'relatively low' dumping charges have less effect in providing incentives to contractors to improve CWM behaviors.*

As shown in Table 8, on-site sorting is largely voluntary, and high labor costs are a disincentive for contractors to undertake this segregation.

4.3.2 Challenging thresholds for certain types of projects

The interviews revealed that it is infeasible for certain types of projects to achieve several thresholds in practice. For example, two criteria in LEED, MR 1.1 and MR 1.2, aim to promote reuse of existing structural/non-structural building components with thresholds at 55% and 50%, respectively. However, as mentioned by the vast majority of interviewees and in Table 8, the volume of new construction is normally so large that the percentage of building reuse cannot reach GBRSs' standards for new buildings. Moreover, most GB projects are new constructions. It is very rare for new projects to obtain these two credits whether in the U.S., Mainland China or Hong Kong.

Only one interviewee discussed a major renovation project with the aforementioned credits gained. This case, in Mainland China, involved converting an old factory into an office building while preserving the original structural skeleton, pillars, walls and stairs. Meanwhile, all windows and doors were replaced.

According to another GB consultant:

> *These credits are highly dependent on the designers' evaluation on the feasibility in preserving existing building elements as well as the very details of demolition, which is an indeed exhausting task. Taking a lot of time and effort, these inconsequential points ask is not an efficient use of resources. Additional buffer points should be included elsewhere as a lot of uncertainty lies in scoring for the points under these credits.*

Similarly, BEAM Plus encourages reuse of the major sub-structure of existing buildings through MA1. Although the threshold is set as 30%, which is lower than that in LEED, significant numbers of projects could not realize this requirement. Relevant provisions of the credits do not exist in GBEL.

4.3.3 Fewer incentives for reuse and recycling of building materials

The three GBRSs have similar emphases on promoting the reuse and recycling of building materials to decrease the consumption of virgin resources, which are embodied in LEED MR3 & MR4, GBEL MM2.12 & MM2.13, and BEAM Plus MA7. These concepts are hardly new but the items listed are scored rarely except LEED MR4 and GBEL MM2.12. Based on the interviews, most projects prefer to use new building materials for a few reasons.

First, stakeholders have concerns over quality and durability of old elements and recycled materials for structural components. Waste materials can be normally used as selected backfill material, aggregated in concrete and concrete blocks and used as materials under roadbeds and in other non-structural components. For structural elements, all interviewees prefer using new, quality-assured building materials. One engineer in Mainland China said:

> *Even though the recycled building materials are certified with quality assurance, we dare not use them, at least for now. Who knows what condition they will be in a couple of decades? Nobody wants to assume the responsibility.*

Another consultant said:

> *Materials which contain recycled contents may not meet the specifications. For instance, concrete wall strength may not be desirable if recycled concrete aggregates are used. Scoring for this aspect will require coordination work with other disciplines.*

Second, it is difficult to convince clients and designers to adopt salvaged materials or recycled materials. The conventional construction mindset in China, fond of the new and tired of the old, is a possible obstacle in that most clients are reluctant to reuse old building elements. As a result, private developers believe that using new building materials will definitely add value to their properties to be sold. A GB consultant based in Hong Kong mentioned:

> *It is dependent on the nature of project. For example, in several hotel and residential projects I have worked on, the clients and designers were less likely to use these 'cheap-looking' components. Plus, reusing old elements and recycling materials does not work as an attraction when it comes to promotion and marketing.*

In addition, the recycled building material market is still in infancy. Based on the interviews, there appears to be few options for obtaining recycled materials particularly in Mainland China and Hong Kong. Contractors prefer to purchase materials from their existing suppliers with whom they have stable long-term business cooperation. It should also be noted that, while some studies indicate that recycled materials are relatively costlier than regular building materials, most of the interviewees considered cost not to be the primary concern in selecting building materials.

4.3.4 Difficulty of data collection during project execution

In accordance with requirements for achieving CWM-related credits in GBRSs, data collection and recording is crucial for documentation and verification. This work needs collaborative cooperation between GB consultants and contractors; the only channel for provision of the necessary data. Yet, the interviews reveal some practical issues. The majority of credits associated with CWM are aimed at evaluating the work carried out by the contractor at the construction stage. The assessment is solely dependent on data and other evidence provided by contractors in the form of a monthly report requested by GB consultants, who meet obstacles in coordinating with contractors to collect the data due to their lack of voice within a GB project. According to the interviewees, contractors often fail to regularly submit reports and consultants have to urge them or even ask clients for their enforcement. This not only increases consultants' workload, but also uncertainty around achieving credits throughout the construction period.

The problem seems to be especially prominent in Mainland China, especially in the private sector. It should be also noted that for GBEL-OL, the assessment on construction waste reduction is made after at least a year of occupancy, making data collection and recording even more difficult. A consultant with experience in both Mainland China and Hong Kong refers to the 'unruly behavior' of contractors in Mainland China and the lack of any means of enforcing data collection. He also describes BEAM Plus as requiring 'exceptionally tedious and tricky paperwork' when it comes to the materials aspect so, "to reduce the uncertainty of construction related credits obtained and our workload on the complex documentation process, we usually give a lower priority for those credits in the beginning so.

In summary, a detailed analysis of the interview data provides an in-depth understanding of why GB ratings systems have a negligible impact on CWM in real practice. Generally, the credits related to CWM are relatively low and difficult to attain. In the design of GBRSs, some of the threshold points are simply too difficult to achieve for certain types of projects. Incentives for reuse and recycling of building materials are lacking, and the documentation process is complex. The authenticity of documentation for GBRSs is also an issue, while obtaining the data from contractors during the construction stage and ensuring its authenticity adds to the transaction cost. Overall, to obtaining CWM-related credits is costlier and more burdensome than achieving other ‘easy’ credits. All of these factors help explain the lack of impact on CWM.

5. Discussion

5.1 Fine-tuning the design of GBRSs

Relevant GB councils (GBCs) can fine-tune GBRSs with a view to enhancing their role in CWM. For example, efforts can be made to increase the weight of material aspects in the overall GBRS. This is particularly urgent for BEAM Plus, which only allocates 8% to the material aspect from which CWM credits mainly derive. Interviewees remarked on how Hong Kong’s Construction Waste Disposal Charging Scheme (CWDCS) has imposed an incentive to better manage construction waste already. CWM has essentially ‘double dipped’, gaining BEAM Plus accreditation and saving on construction waste disposal levies. All this without demanding particularly advanced CWM. It may be unrealistic to increase the administrative incentive so GB stakeholders can completely offset the costs of pursuing more progressive

CWM. However, given this study's testimonials, such a policy would likely have a far greater impact than increasing the weighting of relevant GBRS credits. Greater attention should also be paid to optimizing some of the thresholds interviewees deemed too difficult to achieve and therefore not worth attempting.

Certainly, any small change may have unexpected implications for other CWM measures, or material aspects, or even other goals, e.g., water, energy saving. However, this study supports GBCs revaluating how they weigh their core categories. And, as they release updated versions of GBRSs for new construction, they should also consider making room for preservation of existing structural elements rather than deem Existing Building and New Construction as mutually exclusive building practices.

5.2 Fostering a more amenable environment for improving CWM

Improving CWM cannot solely rely on a GBRS, or the GB movement, which is largely a voluntary premise. Legal and economic tools supplemented by administrative approaches must be adopted. The green agenda must be transformed into contract language so that all project stakeholders will legally bound to guarantee enlightened CWM. In Mainland China, however, only a few advanced cities have regional regulations that require appropriate CWM and the overall development of CWM level is rather low and distinctively uneven across different regions. In Hong Kong, CWM is conducted in a more systematic way, evidenced by a series of public policies which form an effective and interlocking management system [40]. However, GBRSs are not pushing this good note forward. In addition, the current relatively low dumping charges have provided little incentive to contractors to improve their CWM activities. In the U.S., some interviewees believe that the combination of clients unfamiliar with best construction practices, or even construction itself, and contractors uninterested in or more likely unconcerned with CWM, remain the biggest obstacles to responsible CWM. Clients often presuppose CWM plans desired by LEED will prove too costly and so reject CWM in the beginning or value engineer it out as soon as the project meets a budget restraint. In summary, the impacts of GBRSs on CWM cannot be achieved without a broad and amenable set of conditions in place related to legal systems, political climate, and other technological, economic, and social forces.

6. Conclusions

This research first sought to ascertain the effects of green building (GB) on construction waste management (CWM) by comparing three prevalent green building rating systems (GBRSs) and their real-life applications using empirical project data. It was discovered that 88 real-life GB projects consistently scored low in material aspects where CWM-related credits reside. A probe into the real-life CWM scores of the sample GB projects, whenever data allows, confirmed that CWM seems being systematically avoided. This research then tried to understand the reasons behind this unexpected phenomenon using interviews and qualitative and quantitative data triangulations. It was discovered that such factors as the lack of incentives from scoring methods, the high cost of obtaining CWM-related credits, apprehensions around reusing and recycling building materials, and the complexity of documentation processes are at play to lead to the phenomenon.

Two generic strategies were recommended to achieve continued improvement in CWM via GBRSs. The primary focus should be on adopting progressive legal and economic tools supplemented by administrative approaches to strengthen and monitor CWM. As such, it is important to put the green agenda into contract language so that all project stakeholders commit to CWM. The second is to further fine-tune GBRSs, for example, by increasing the applicable credits and corresponding weights for CWM so that project participants feel incentivized to obtain these credits. They should also push projects toward adopting reusable and recyclable building materials, as well as manufacturing to increase supply of recycled contents.

The limitations of this research and the further studies are suggested as follows. First, it is recommended to develop a framework for delineating a hierarchy of factors impacting CWM performance in GB. This would enable stakeholders to prioritize mechanisms for improving CWM performance in order to comply with GBRSs. Second, case studies could be used to empirically examine how GB affect CWM-related credits with or without GBRSs. This would also help clarify what elements influence stakeholders' decision-making around targeting CWM credits. Lastly, the impacts of GBRSs on CWM in other economies can be examined and compared to discover insights. Cross country learning is often recommendable.

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Table 1 Information about the interviewees

No.	Role	County / Region	Relevant working experience	No.	Role	County / Region	Relevant working experience
1	GB expert, architect, committee member of China GBC	MC & HK	> 12 years	12	Engineering director in a national leading construction firm	MC	> 12 years
2	Consultant in a world leading engineering consultancy firm	MC & HK	> 8 years	13	Consultant in several world leading consultancy firms	HK & SG	> 8 years
3	Consultant in a local GB consultancy firm	MC & HK	> 5 years	14	Consultant in a local leading environmental consultancy firm	HK	> 5 years
4	Consultant in a local consultancy firm	MC	> 4 years	15	Consultant in several world leading environmental consultancy firms	HK	> 4 years
5	Consultant in a national leading architecture institute	MC	> 6 years	16	Environmental officer in a local leading construction firm	HK	> 6 years
6	Consultant in a world leading engineering consultancy firm	MC	> 4 years	17	Environmental project engineer in a regional leading construction firm	HK	> 4 years
7	Engineer in a regional comprehensive design firm	MC	> 15 years	18	Program manager engaged in multiple LEED-certified projects	U.S.	> 15 years
8	GB expert, senior engineer in a regional architecture institute	MC	> 15 years	19	Vice President of Project Services in a construction firm and USGBC spokesman	U.S.	> 15 years
9	Research fellow in a regional architecture institute	MC	> 5 years	20	Vice President of Project Services in a construction firm and USGBC spokesman	U.S.	> 5 years
10	GBEL expert in a HKGBC	MC	> 8 years	21	LEED expert and sustainability director for a major architecture firm	U.S.	> 8 years
11	Project manager in a national leading construction firm	MC	> 20 years	22	Spokesman for a government environmental office and GB policy	U.S.	> 20 years

Note: GBC denotes Green Building Council; MC denotes Mainland China; HK denotes Hong Kong; and SG denotes Singapore

Table 2 The credits allocated to CWM in the LEED

Overall assessment framework			CWM-associated credits		
Performance category		Attainable points	Credit criteria		Attainable points
1	sustainable sites (SS)	26	MR1.1	Building reuse - Maintain existing walls, floors, and roof	3
2	water efficiency (WE)	10	MR1.2	Building reuse - Maintain existing interior nonstructural elements	1
3	energy and atmosphere (EA)	35	MR2	Construction waste management	2
4	**materials and resources (MR)**	**14**	MR3	Materials reuse	2
5	indoor environmental quality (IEQ)	15	MR4	Recycled content	2
6	innovation and design process	6	MR6	Rapidly renewable materials	1
7	regional priority	4			
	Total	110			11

Bold Indicates: CWM-related information.

Table 3 The credits allocated to CWM in the GBEL

Overall assessment framework				CWM-associated credits		
	Performance category	Attainable points	Weighting (%)	Credit criteria		Attainable points
1	land saving & outdoor environment (LO)	100	DL:18.5 OL:15	MM1.2	High strength steels at the 400 MPa yield strength level	Prerequisite
2	energy saving & energy utilization (EE)	100	DL:26 OL:21	MM1.3	Plain architectural design, minimum decorative building components	Prerequisite
3	water saving & water resource utilization (WW)	100	DL:19 OL:15	MM2.1	Regular shaped building	9
4	**material saving & material resource utilization (MM)**	**100**	**DL:18** **OL:14.5**	MM2.2	Optimal structural design	5
5	indoor environmental quality (IEQ)	100	DL:18.5 OL:15.5	MM2.3	Integration of construction and interior design	10
6	**construction management (CM; for OL only)**	**100**	**DL: -** **OL:10**	MM2.4	Adaptability and deconstruction	5
7	operation management (OM; for OL only)	100	DL:- OL:10	MM2.5	Prefabrication	5
8	promotion and innovation	10		MM2.8	Pre-mixed concrete	10
				MM2.9	Ready-mixed mortar	5
				MM2.10	High performance building structural materials	10
				MM2.11	High durable building structural materials	5
				MM2.12	Reusable or recyclable materials	10
				MM2.13	Materials produced by construction waste	5
				MM2.14	High durable and maintainable decoration material	5
				CM2.3	Establishing and implementing the plan for the construction waste management	10
				CM2.6	Reducing the wastage of pre-mixed concrete	6
				CM2.7	Reducing the wastage of steel	8
				CM2.8	Use of metal formwork	10
	Total	DL: 510 OL: 710				DL: 84 OL: 118

Note: DL denotes GB Design Label; OL denotes GB Operation Label

Bold Indicates: CWM-related information.

Table 4 The credits allocated to CWM in the BEAM Plus

Overall assessment framework				CWM-associated credits		
Performance category		Attainable points	Weighting (%)	Credit criteria		Attainable points
1	site aspect (SA)	22+3B	25	MA P1	Building reuse - Timber used for temporary works	Prerequisite
2	**materials aspects (MA)**	**22+1B**	**8**	MA P3	Construction/demolition waste management plan	Prerequisite
3	energy use (EU)	42+2B	35	MA P4	Waste recycle facilities	Prerequisite
4	water use (WU)	9+1B	12	MA1	Building reuse	2+1B
5	indoor environmental quality (IEQ)	32+3B	20	MA2	Modular and standardized design	1
6	innovations and additions	5B+1P	-	MA3	Prefabrication	2
				MA4	Adaptability and deconstruction	3
				MA5	Rapidly renewable materials	2
				MA7	Recycled materials	3
				MA10	Demolition waste reduction	2
				MA11	Construction waste reduction	2
	Total	127+15B+1P				17+1B

Note: B denotes Bonus; P denotes BEAM Professional

Bold Indicates: CWM-related information.

Table 5 The credits distribution of LEED-certified projects in the U.S., Mainland China and Hong Kong

Country / Region	Certification Level	No. of projects	Average Overall Score	SS (%)	WE (%)	EA (%)	MR (%)	CWM (%)	IEQ (%)
U.S.	Platinum	31	83.81	79.78	78.06	84.42	45.16	34.05	45.02
Mainland China	Platinum	18	82.39	85.68	97.78	72.06	42.86	38.43	43.72
Hong Kong	Platinum	4	81.00	94.87	100.00	55.00	39.00	27.04	58.00
Average	-	-	-	86.78	91.95	70.49	**42.34**	**33.17**	48.91

Note: SS = sustainable sites; WE = water efficiency; EA = energy & atmosphere; MR = materials & resources; IEQ = indoor environmental quality

Data Source: Public data posted on the official website of the U.S. GB Council

Table 6 The credits distribution of GBEL-certified projects in Mainland China

Certification Level	No. of projects	Average Overall Score	LO (%)	EE (%)	WW (%)	MM (%)	CWM (%)	IEQ (%)	P&I
3 Star - DL	2	82.88	81.13	77.10	92.44	69.36	73.89	76.28	4.00
2 Star - DL	6	63.29	66.86	56.86	75.07	56.38	40.83	58.05	2.00
Average	-	-	74.00	66.98	83.76	**62.87**	**57.36**	67.16	3.00

Note: LO = land saving & outdoor environment; EE = energy saving & energy utilization; WW = water saving & water resource utilization; MM = material saving & material resource utilization; IEQ = indoor environmental quality; P&I = promotion & innovation; DL = GB design label

Data Source: Several GB consultancy firms in Mainland China

Table 7 The credits distribution of BEAM Plus-certified projects in Hong Kong

Certification Level	No. of projects	Average Overall Score	SA (%)	MA (%)	EU (%)	WU (%)	IEQ (%)	I&A
Final Platinum	11	81.09	77.82	47.18	81.27	65.18	81.73	5.27
Provisional Platinum	11	83.00	78.36	38.82	82.36	72.55	85.36	5.64
Final Gold	3	68.67	66.00	43.00	67.33	58.67	75.33	3.00
Provisional Gold	1	72.00	67.00	38.00	71.00	71.00	79.00	4.00
Final Silver	1	56.00	50.00	18.00	54.00	71.00	54.00	4.00
Average	-	-	67.84	**37.00**	71.19	67.68	75.08	4.38

Note: SA = site aspects; MA = materials aspects; EU = energy use; WU = water use; IEQ = indoor environmental quality; I&A = innovations and additions

Data source: Public data posted on the official website of the Hong Kong GB Council

Table 8 Summary of findings from semi-structured interview series

GBRS	**LEED**			**GBEL**	**BEAM Plus**
Country / Region	Mainland China	Hong Kong	U.S.	Mainland China	Hong Kong
Scoring of the rating system					
● Threshold for credit of Building Reuse	Hardly achievable	Hardly achievable	Hardly achievable	N/A	Hardly achievable
● The value of “materials” performance credits compared to the total GB score	No weighting, i.e., 1 credit equals 1 point earned in total score	No weighting, i.e., 1 credit equals 1 point earned in total score	No weighting, i.e., 1 credit equals 1 point earned in total score	Moderate weighting, i.e. 1 credit equals slightly less than 1 point earned	Sizable weighting, i.e. 1 credit equals less than 1 point earned
● Difficulty in documentation process	Moderate	Moderate	Moderate	Data retention for Operation Label	Complicated
Coordination between contractors and GB consultants					
● The stage GB consultant involved in the project	Majority from design stage	Design stage	Design stage	Majority from design stage	Design stage
● Person in charge of coordinating with GB consultant	On-site engineer	Environmental Officer	Project Manager or on-site engineer	On-site engineer	Environmental Officer
● Frequency of in-person meeting	Based on request	Monthly	Biweekly	Based on request	Monthly
Reuse of salvaged materials					
● SOP of demolition work for waste reduction	No	No	No	No	No
● Concerns from stakeholders	Quality & Durability	Quality & Durability & Cheap-looking	Quality & Durability	Quality & Durability & Cheap-looking	Quality & Durability
● Reuse of concrete	Partially for backfill or other uses	Partially for backfill or other uses, possibly services different project sites	Partially for backfill or other uses, possibly services different project sites	Partially for backfill or other uses	Partially for backfill or other uses, possibly services different project sites
Recycled building materials					

● Options in the market	Few	Few	Moderate	Few	Few
● Consideration on cost factor	Minimal	Minimal	Minimal	Minimal	Minimal
● Concerns from stakeholders	Quality	Cheap-looking	Quality & availability	Quality	Cheap-looking
Disposal of construction waste					
● On-site sorting	Voluntary action	Required by government	Required by local government	Voluntary action	Required by government
● Waste classification	"Can be sold" or not	Inert / Non-inert / Metallic and subcategories	Reusable/Recyclable and subcategories within that	"Can be sold" or not	Inert / Non-inert / Metallic and subcategories
● Supervision on waste dumpling	Insufficient	Stricter	Moderate	Insufficient	Stricter
● Site workers factors	Uneven quality	Labor cost	Labor cost	Uneven quality	Labor cost