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Construction waste minimization in green building: A comparative analysis of LEED-NC 2009 certified projects in the US and China

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ABSTRACT

Construction waste minimization is a key sustainability goal in green building rating systems. Although these rating systems traverse countries' boundaries, no research so far has compared construction waste minimization performance in such systems across countries. This research aims to investigate and compare the construction waste minimization performance of green building projects in the US and China by focusing on the widely adopted LEED (Leadership in Energy and Environmental Design) certification system. Data on 599 and 297 LEED-New Construction (NC) 2009 certified projects in the US and China, respectively, were sourced from the US Green Building Council project directory. Their construction waste minimization-related points were compared using the Mann-Whitney *U* and effect size test, and semi-structured interviews were conducted to identify the possible causes behind statistical analysis results. We found no significant difference in construction waste minimization performance of LEED platinum-level projects in the US and China, but the magnitude of the difference between two countries increased as the certification level went lower. The enforcement on regulations, recycling market development, public consciousness and advanced technologies lead to the differences while the influence of the political, economic, social, and technological context increased when the projects were certified with lower LEED levels. An amenable context should be fostered to achieve a better construction waste minimization performance in green building and a sustainable development goal.

1. Introduction

Construction is a pillar industry that materializes the built environment, boosts economies, and provides jobs (Hillebrandt, 1984). It also has a negative impact on the natural environment, for instance through land depletion and degradation, solid waste generation, dust and gas emissions, and consumption of non-renewable natural resources (Lu et al., 2015b; Shen et al., 2007). For example, the construction and operation processes of buildings were responsible for 39% of energy-related carbon dioxide (CO_2) emissions in 2017 (Global ABC, 2018), while in most developed countries construction contributes 20–30% of solid waste ending up in landfills (Lu et al., 2018). The question of how to maximize the positive role of construction while minimizing its negative impacts has received considerable attention, with many construction-related institutions now prioritizing sustainable, or green, building.

Buildings are designed, built, and operated according to codes. Green buildings go beyond conventional codes, having higher sustainability goals in energy saving, carbon emission reduction, and indoor air quality improvement. As a result, green building rating systems have been developed to evaluate and certify projects on a voluntary yet market-based premise (Illankoon and Lu, 2019). Prominent are China's Green Building Evaluation Label (GBEL), Australia's Green Star, the European Building Research Establishment Environmental Assessment Method (BREEAM), and Hong Kong's Building Environmental Assessment Method (BEAM) Plus. The US-led Leadership in Energy and Environmental Design (LEED) has the greatest market penetration globally (MacNaughton et al., 2018). As of 2018, over 94,000 commercial buildings in 165 countries including the US, China, India, Brazil, Turkey and Germany had subscribed to LEED certification (USGBC, 2019a).

Stewardship of construction resource, material and waste is an important aspect of 'going green'. The term 'construction waste'

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refers to surplus and abandoned materials resulting from building activities including construction, renovation, and demolition (HKEPD, 1998). All green building standards have credits assessing waste management and minimization, with the aim of reducing virgin resource consumption and landfill use. To obtain points related to construction waste minimization, building clients can reuse original building components, use green materials, adopt low-waste design and construction technologies, and devise better waste management plans. Since waste minimization initiatives normally contribute 8–12% of all attainable points in a green building rating system (Wu et al., 2016), examining the performance in this area is of relevance, interest and importance.

Many studies have compared green building rating system performance categories. For example, Roderick et al. (2009) investigated energy consumption within the LEED, BREEAM and Green Star schemes. Orova and Reith (2013) evaluated neighbourhood sustainability across five rating systems. Wu et al. (2016) compared construction waste minimization assessment principles in five green building rating systems, and Lu et al. (2019) evaluated waste minimization performance under LEED, BEAM Plus and GBEL. Some studies have compared the rating system performance within a country; for example, Pushkar and Verbitsky (2019) discovered that the cross-certification performance in LEED projects in the US reflected the same strategy in the same state. However, there appears to be minimal research comparing the effect of a particular rating system on minimization of construction waste in different economies. Uncovering how the same rating system performs differently in different regions will provide support for the argument that green building rating systems need to be adapted for the local context in which they are applied (Albino and Berardi, 2012; Gou and Lau, 2014). It also presents an opportunity to examine how different political, economic, social, and technological (PEST) conditions influence the implementation of construction waste minimization practices within rating systems. Since it is the world's most widely recognized green building rating system, this study probes waste minimization performance under LEED.

This research aims to investigate and compare construction waste minimization performance of LEED-certified projects in the US and China. We choose these two contexts for two reasons. Firstly, LEED has the most registered green building projects in these countries. As of 2018, 33,632 projects in the US and 1,494 projects in China were LEED-certified (USGBC, 2019b). Secondly, the two countries are of a similar geographic size but dissimilar in PEST context, allowing for potentially revealing comparisons to be made. The rest of the paper is organized as follows. Subsequent to this introductory section is a literature review on green building and green building rating system, and construction waste minimization. Section 3 introduces the research method, a combination of quantitative analyses and semi-structured interviews. Data analyses, results, and findings are presented in Section 4. Section 5 discusses the findings and conclusions are presented in Section 6.

2. Literature review

2.1. Green building and green building rating system

The concept of green building still lacks a clear definition. Kibert (2016) defines green building as "healthy facilities designed and built in a resource-efficient manner, using ecologically based principles". Howard, 2003 definition emphasizes the efficient use of energy, water and materials and reduced impacts on human health and the environment throughout the building life cycle. This life cycle perspective factors into the US Environmental Protection Agency (USEPA) (2016) definition of green building, which emphasizes environmental responsibility and resource efficiency, as well as Adler et al.'s (2016) characterization of green building as a holistic practice aimed at achieving sustainability in planning, design, construction, operation and maintenance, demolition and waste treatment.

To promote design and construction beyond regulatory minimums towards a green standard (Fowler and Rauch, 2006), various rating systems, sometimes called 'sustainability assessment rating systems' (Berardi, 2012), have emerged recently to serve as comprehensive mechanisms for assessing and recognising the level of 'greenness' achieved by a building (Shan and Hwang, 2018). A green building rating system includes a set of explicit performance categories as well as criteria that can help ensure buildings meet or exceed designated performance thresholds (Mattoni et al., 2018), and is structured to cope with diverse aspects of building performance relating to energy, site, indoor air quality, materials and other attributes of sustainable design (Doan et al., 2017; Gowri, 2004; Lu et al., 2019).

Researchers have examined the effects of green building rating systems on a variety of aspects, including energy efficiency (Castleton et al., 2010), indoor environmental quality (Abbaszadeh et al., 2006; Allen et al., 2015), residents' health (Colton et al., 2015; Zhang and Altan, 2011), and carbon emissions (Shuai et al., 2017; Zhang et al., 2014). Some researchers have extended their studies to explore green building rating system effects on sustainable development, since they are regarded as a 'sustainable management tool' to assist green or sustainable building development (Zuo and Zhao, 2014). For example, Berardi (2015) classifies green building rating system into total quality assessment systems to evaluate dimensions of sustainability, including ecological, economic, and social aspects; Ismaeel (2018) addresses approaches adopted by green building rating systems for environmental problems; and several studies have explored the management or minimization of construction waste via investigations of green building rating systems (e.g. Wu et al., 2016; Lu et al., 2019).

2.2. Construction waste minimization

Construction waste is the solid waste resulting from construction, renovation and demolition activities, normally classified as inert or non-inert depending on stability of its chemical properties (HKEPD, 1998). Landfilling is the usual means of dealing with non-inert waste (Lu et al., 2011; Wu et al., 2019), but is criticized for its negative socio-economic effects and causing environmental degradation (Lu et al., 2015a). Inert waste, on the other hand, can be reused or recycled for land reclamation and site formation (Lu et al., 2017), but a proper means of construction waste management is needed for the reused or recycled purpose.

Many studies have been conducted on construction waste management (e.g. Shen et al., 2004; Lu and Yuan, 2011; Lu et al., 2015a). Over time, the focus has refined into the discipline of construction waste minimization defined by Osmani (2012) as "the reduction of waste at source by understanding its root causes and re-engineering current processes and practices to alleviate its generation". Wang et al. (2019) define construction waste minimization as "taking all feasible technical means and management measures for reducing or avoiding the generation of construction waste in the whole process of construction implementation".

Emerging studies (e.g. Wu et al., 2016; Chen et al., 2018; Lu et al., 2018; Lu et al., 2019) have examined construction waste minimization of green building. This is a major sustainability goal prescribed by most green building rating systems, usually embedded in the material utilization category and accounting for a non-negligible portion of credits. For example, 23 points in BEAM Plus are allocated to the material aspect, of which 18 are attainable via construction waste minimization. For GBEL, which has 510 points in total, 84 of the 100 points allocated to materials are construction waste minimization related (Lu et al., 2019). Under LEED-New Construction (NC) 2009, the focus of this study, 14 out of 110 points are allocated to materials and resources (see the yellow square in Fig. 1). Credits associated with construction waste minimization are based on the 3Rs (reduce, reuse and recycle) (Wu et al., 2016). For example, MR6 (Rapidly renewable materials) is designed to reduce use of finite raw materials and instead install specified short-cycle materials. MR1.1, MR1.2, MR2, MR3, MR4, and MR6 (the blue squares in Fig. 1), are identified as construction waste minimization-related credits, totalling 11 points.

3. Research methods

3.1. Data and samples

Given that so few projects have so far achieved LEED v4 certification, this research considers green building projects certified under LEED-NC 2009. Data on these projects in the US and China were sourced from the project directory of the US Green Building Council (USGBC), resulting in a sample of 599 and 297 projects from the US and China respectively (896 in total) plotted on maps, in Fig. 2. The sampled green buildings in the US are located across states with California having the highest concentration, while those in China are concentrated in economically developed eastern coastal provinces and cities such as Jiangsu, Guangdong, Beijing, and Shanghai. The numbers of projects, average attained construction waste minimization (CWM)-related points, and average attained overall points are shown in Table 1. Under LEED, there are four certification levels: platinum, gold, silver and certified. The overall score attained of projects at each certification level in the US and China are equal, which ensures that the two sets of samples are comparable.

3.2. Statistical methods for comparative analysis

To compare construction waste minimization performance of the sampled LEED-certified projects in the US and China, several statistical tests were applied to see whether a statistically significant difference exists at each certification level or not. Normality of the groups of data was checked first using the Kolmogorov-Smirnov (K–S) test and the Shapiro-Wilk test. The K–S test compares the cumulative distribution of the data with the expected cumulative normal distribution (Öztuna et al., 2006). The Shapiro-Wilk test depends on the correlation between given data and their corresponding normal scores. We apply these tests in the study assuming the null hypothesis of a normal distribution. The results in Table 2 indicate that all groups of data reject the null hypothesis with p-values less than 0.5 and are distributed non-normally.

Due to the non-normal distribution results, the non-parametric Mann-Whitney *U* test is applied to determine if the construction waste minimization performance of LEED-certified projects in the US and China are significantly different from each other at different certification levels. This test initially indicates the calculation of a *U* statistic of each group. Mathematically, the statistics are defined by the following equations for each group:

$$U_1 = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R1 \quad \text{Equation 1}$$

$$U_2 = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R2 \quad \text{Equation 2}$$

where n_1 and n_2 are the sample sizes of the two groups, and R_1 and R_2 indicate the respective sum of ranks assigned to the two groups. We obtain two different values from Equations (1) and (2), i.e. U_1

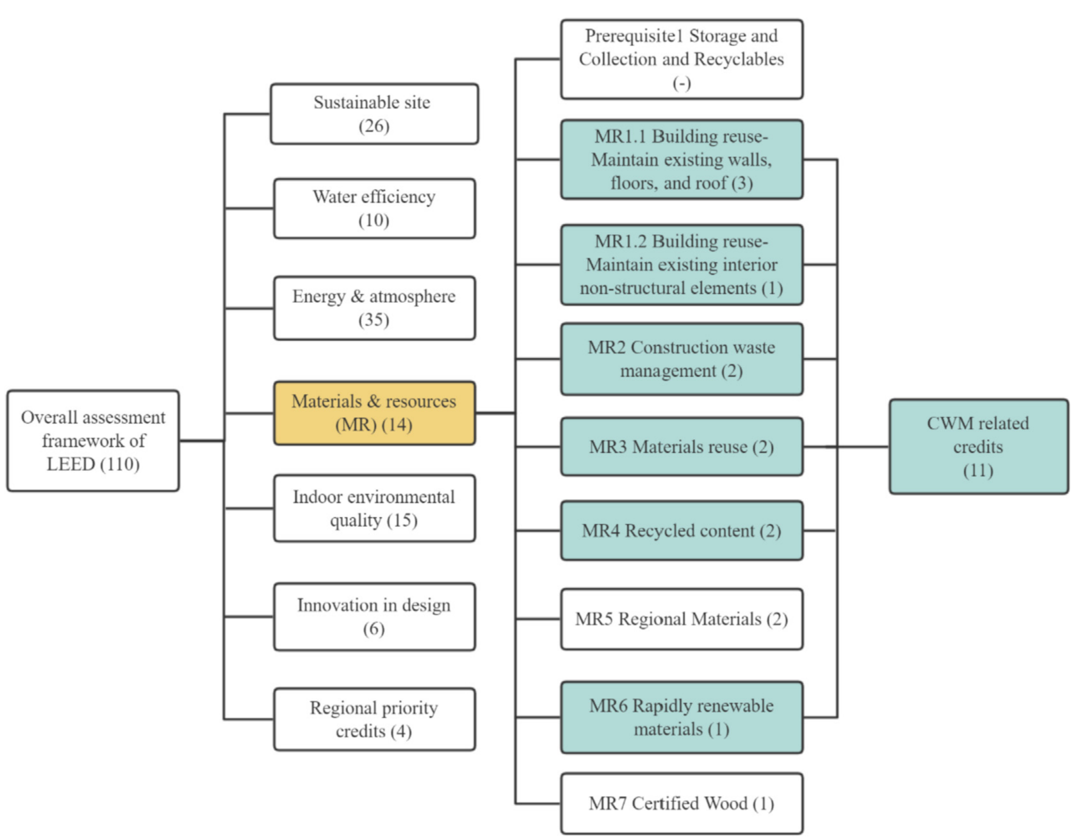

Fig. 1. Construction waste minimization-related credits under LEED-NC 2009. (The numbers in brackets denote the attainable points).

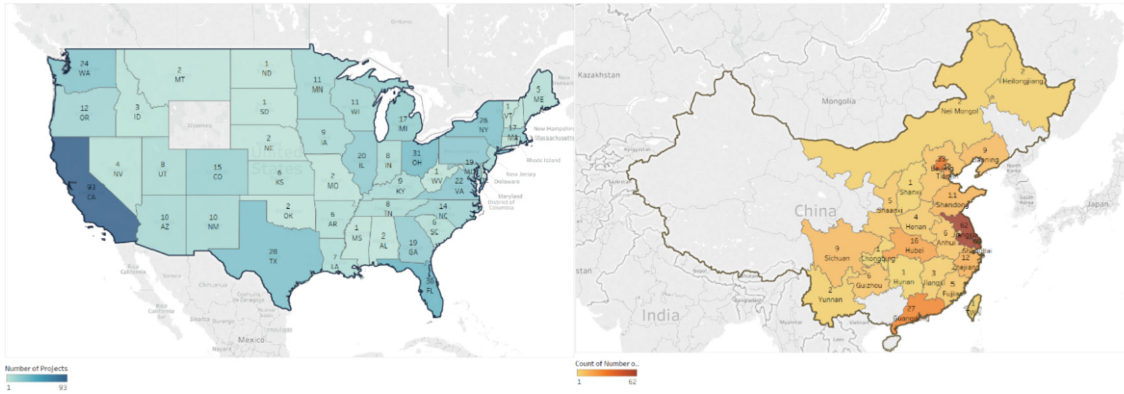

Fig. 2. Distribution of sampled LEED-certified projects in the US and China.

Table 1
Overall score and CWM-related points of sampled LEED-certified projects based on certification levels.

Certification Level	US			China		
	No. of projects	Average CWM-related points obtained	Overall score obtained	No. of projects	Average CWM-related points obtained	Overall score obtained
Platinum	55	4.036	82.00	32	3.781	82.56
Gold	190	3.968	64.00	147	3.578	64.64
Silver	247	3.619	54.00	89	3.180	54.16
Certified	107	3.598	45.00	29	2.793	45.07
Total	599	–	–	297	–	–

Data source: The USGBC project directory (https://www.usgbc.org/projects).

Table 2
Results of normality tests for CWM-points obtained.

Country	Certification level	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	p-value	Statistic	df	p-value
US	Platinum	0.328	55	2.14e-16	0.836	55	3e-6
	Gold	0.270	190	9.12e-39	0.908	190	1.77e-9
	Silver	0.253	247	3.93e-44	0.897	247	6.32e-12
	Certified	0.213	107	6.12e-13	0.933	107	4.5e-5
China	Platinum	0.396	32	3.03e-14	0.733	32	3e-6
	Gold	0.310	147	8.37e-40	0.740	147	7.62e-15
	Silver	0.227	89	2.58e-12	0.853	89	6.36e-8
	Certified	0.258	29	3.3e-5	0.896	29	7.88e-3

[a] Lilliefors Significance Correction.

and U_2. The final value of U is taken as the minimum between U_1 and U_2, $U = \min(U_1, U_2)$.

To further illustrate the magnitude of differences and complement the results of the Mann-Whitney U test, Cliff's delta (d) reports effect size without requiring any assumptions about the shape of the two distributions (Cliff, 1993). It is linearly related to the Mann-Whitney U statistic, expressed as:

$$d = \frac{2U}{n_1 n_2} - 1 \qquad \text{Equation 3}$$

where d is Cliff's delta, U is the Mann-Whitney U statistic, and n_1 and n_2 are the sample sizes of the two groups. Magnitude is usually assessed using the thresholds provided in Romano et al. (2006), i.e. $|d|<0.147$ “negligible”, $|d|<0.33$ “small”, $|d|<0.474$ “medium”, and otherwise “large”.

3.3. Semi-structured interview

Semi-structured interviews were undertaken to probe industry practices in the US and China and uncover possible causes of the construction waste minimization performance of projects at different LEED certification levels. We conducted a combination of face-to-face and Skype interviews between October 2018 and March 2019 with a total of 16 green building experts, consultants, contractors and directors of construction waste recycling companies. The interviewees' basic profiles are summarized in Table 3. Each interview lasted around one hour, and five to ten pre-arranged open-ended questions were asked. Based on the interviewees' responses, the questions were extended to mine further insights.

A complete list of LEED credits was provided along at the interview so that we could confirm if we omitted any relevant CWM-related credits identified. The interviewees interpreted the rationales of these credits one by one, and then shared practical experience and difficulties achieving these credits in real-life projects. The interviewees further shared their views on barriers to improving construction waste minimization performance in LEED-certified projects and other important institutional factors arising from their PEST context, such as building codes, regional construction standards, economic development, social awareness of

Table 3
Profiles of the interviewees.

No	Role	Country	Relevant working experience
1	Representative in the US Environmental Protection Agency and in charge of green building policy	US	>20 years
2	GBC spokesman & vice president in a construction firm	US	>15 years
3	Program manager in an engineering team & multiple LEED project	US	>15 years
4	Green building expert and sustainability director in an architecture firm, AIA, LEED AP	US	>8 years
5	GBC spokesman & vice president in a construction firm	US	>5 years
6	Consultant in an engineering consultancy firm, LEED AP	China	>8 years
7	Consultant in a green building consultancy firm, LEED AP	China	>5 years
8	Consultant in an architecture institute, LEED AP	China	>6 years
9	Consultant in a comprehensive design firm, engineer	China	>15 years
10	Green building expert in an architecture firm, architect, LEED AP	China	>12 years
11	Green building expert in an architecture institute, LEED AP, engineer	China	>15 years
12	Green building expert in the GBC, architect, LEED AP	China	>8 years
13	Project manager in a construction firm, engineer	China	>20 years
14	Director in a real estate development firm, engineer	China	>12 years
15	Construction waste minimization researcher in an architecture institute	China	>5 years
16	Director in a construction waste recycling firm	China	>10 years

Note: GBC denotes the US Green Building Council; AIA denotes the American Institute of Architects; LEED AP denotes LEED Accredited Professional.

construction waste treatment, and technical obstacles for the recycling industry.

After reviewing the construction waste minimization data garnered from these interviews, we formulated more specific questions for a second round of interviews, e.g.:

- Which credits were most difficult to obtain in the context of China?
- What are the obstacles?
- How is construction waste minimization considered at each stage in the project lifecycle?
- Is on-site sorting of construction waste well executed?
- How is data collection undertaken in line with LEED requirements?
- Do you have any novel approaches to encourage stakeholders to adopt recycled building products?

4. Data analyses, results and findings

4.1. The Mann-Whitney U test on construction waste minimization performance at four certification levels

The descriptive statistics of the two groups (i.e. the US and China) at the four LEED certification levels are presented in Table 4 with the number of projects in each country, the median and interquartile ranges. The medians of CWM-related points for green building projects in the US and China are the same point (i.e. 4) at platinum and gold certification levels, whereas the medians of US projects are higher than China projects at the lower levels: silver and certified. The maximum CWM-related points of the US projects are higher than those in China at all certification levels.

The Mann-Whitney *U* and effect size test results are presented in Table 5. There is no significant difference for the projects at the platinum level, which implies that when the project is awarded platinum, construction waste minimization performance is fully considered whether the project is located in the US or China. At the certification levels of gold ($U = 11903$, $p = 0.0114$), silver ($U = 8854$, $p = 0.0041$), and certified ($U = 1092.5$, $p = 0.011$), the US projects perform significantly better than those in China at the 0.05 level, although the effect sizes represented by Cliff's delta estimates are small based on the thresholds provided in Romano et al. (2006), which shows that the magnitude of difference is small. However, the thresholds as generic descriptions of the magnitude of effect size may be misleading, since some research areas are likely to have smaller effect sizes than others (Valentine and Cooper, 2003). Therefore, following Cohen (1988) in interpreting effect size estimates relative to other effect sizes, the effect sizes of the four certification levels are compared. We find that the effect size increases when the certification level is lower; in other words, there is no significant difference in construction waste minimization performance in the US and China at the platinum level, but the magnitude of the difference between the two countries increases when the projects are awarded lower certification level.

Table 4
Descriptive statistics of the construction waste minimization performance for LEED-certified projects at each certification level in the US and China.

Certification levels	Country	No. of projects	Min	Q1	Median	Q3	Max
Platinum	US	55	1	3	4	4	8
	China	32	2	4	4	4	5
Gold	US	190	0	3	4	4	9
	China	147	0	3	4	4	7
Silver	US	247	0	3	4	4	9
	China	89	1	3	3	4	6
Certified	US	107	0	2.5	4	4	8
	China	29	0	2	3	4	5

4.2. Detailed CWM-related points

To better understand construction waste minimization performance in the US and China under each assessment credit, details of CWM-related points obtained by the 896 green buildings were sourced from the official webpages of the USGBC. Table 6 compares CWM-related credit distribution of LEED-certified projects in the US and China. The meanings of the credits are provided in Fig. 1. To reflect construction waste minimization performance for each assessment credit, the scoring rate (obtained points/attainable points) instead of obtained points is used, since attainable points for each credit varies, e.g., there are 3 attainable point(s) for MR1.1 and 1 for MR1.2.

At the platinum level, US projects scored higher than projects in China in MR1.1, MR1.2, and MR3 (all of which concern building or material reuse), but the projects in China perform better in MR2, MR4 and MR6 (regarding waste management and recycled content). This may be why there is no significant difference between the two countries overall for platinum-level projects as shown in Table 5. While the US projects remain a good performance at the levels of gold, silver, and certified in MR1.1, MR1.2, MR4, and MR6, the scoring rate for China projects decreases significantly at these certification levels. These four credits account for a large

Table 5
The Mann-Whitney *U* and effect size test results under each certification level.

Certification level	Mann-Whitney U test[a] Mann-Whitney U statistic	p-value	Effect size test Cliff's Delta estimate	Assessments[b]
Platinum	886	0.9572	−0.0068	negligible
Gold	11903	0.0114*	0.1477	small
Silver	8854	0.0041**	0.1945	small
Certified	1092.5	0.011*	0.2958	small

*, **, *** indicate significance at the 0.05, 0.01, 0.001 levels, respectively.
[a] Alternative hypothesis: true location shift is not equal to 0.
[b] The assessments are based on the thresholds provided in Romano et al. (2006).

Table 6
The scoring rate of CWM-related credits of LEED-certified projects in the US and China.

CWM-related credits (Attainable points)	Country	The scoring rate			
		Platinum	Gold	Silver	Certified
MR1.1 (%)	US	16.67	20.18	13.63	20.56
(3)	China	0	2.74	1.12	2.3
MR1.2 (%)	US	3.7	0	1.01	1.87
(1)	China	0	0.34	0	0
MR2 (%)	US	90.74	88.16	88.46	78.04
(2)	China	96.88	94.9	91.01	84.48
MR3 (%)	US	6.48	0.79	1.21	0.47
(2)	China	1.56	0	0	1.72
MR4 (%)	US	75.93	78.16	69.64	68.22
(2)	China	87.5	78.91	66.29	50
MR6 (%)	US	3.7	2.11	0.4	0.93
(1)	China	6.25	1.36	0	0

Data source: The USGBC project directory (https://www.usgbc.org/projects).

proposition of CWM-related credits: there are 7 attainable points for these four credits, and 11 attainable points for CWM-related credits in total. The scoring rate for projects in China is slightly higher than that for the US projects in MR2 (2 attainable points) at the certification levels of gold, silver, and certified. In summary, while the US projects perform similarly at all four certification levels, there is a great disparity in construction waste minimization performance of projects in China at different certification levels. This is why the magnitude of the difference between the two countries increases when the projects have been awarded a lower certification level.

4.3. Discrepancies in construction waste minimization performance explained

As shown in Table 6, the biggest differences between green buildings in the US and China are seen in the credits MR1.1 (Building reuse -Maintain existing walls, floors and roof) and MR1.2 (Building reuse -Maintain existing interior non-structural elements). LEED-certified projects in China, especially those with a low certification level, barely obtain these two credits. According to LEED criteria, these credits are meant to encourage the reuse of existing or previously occupied building components, with the reuse portion for structural and non-structural components reaching the thresholds of 55% and 50%, respectively. Interviewees suggested that the volume of new construction projects in China makes it hard to reach these reuse thresholds. According to a green building consultant and architect based in China, "*The majority of top-ranked LEED buildings are new construction projects in large scale. Some projects are considered as landmark projects aiming at 'the bigger, the better' to showcase their business value and responsibility to the society*". Moreover, China's rapid urbanization and economic expansion leads to urban renewal. Most old buildings are dismantled to free up land for new buildings without considering their reuse value; a possible explanation for why even platinum-accredited projects in China have not obtained points under MR1.1 or MR1.2 (see Table 6).

Being at a different stage in its socio-economic development compared to China, the speed of urbanization in the US has decreased in recent decades. US public authorities may employ different strategies and have different priorities for urban development, e.g., undertaking old building renovation and urban regeneration instead of large-scale 'destruction and build', and making full use of existing land and resources in line with sustainable urbanism. Sharing his experience of building project reuse, a US project manager said, "*Roughly half of major projects concern foundation and structural reuse*". Unlike China, the volume of projects is limited in the US. Said one interviewee, "*Height restrictions are enforced by using the urban land outside the central business district which limit the overall volume of a project*". Due to the limited volume of projects in the US, it is easier to reach the component reuse thresholds set in the LEED than in projects in China.

There are several other barriers to achievement of MR1.1 and MR1.2, which largely rely on the detailed and complex design of demolition/deconstruction works with reference to original design documentation (Couto and Couto, 2010). However, lack of design drawings, lack of regulations, and potential extra time cost hinder the implementation of demolition works in accordance with LEED criteria in China. Interviewees from the China projects mentioned these problems frequently, while American interviewees rarely did.

The credits MR3 (Materials reuse) and MR4 (Recycled content) promote the use of salvaged, refurbished or reused materials and adoption of building products incorporating recycled content. As per the interviews, there are a few possible causes for the relatively low points scored by the China projects, especially for *MR3*. Firstly, project stakeholders distrust the quality and durability of recycled materials. Secondly, some interviewees mentioned the vast majority of developers prefer brand-new building products, influenced by the typical Chinese conceptions, “fond of the new and tired of the old” and “new is better”. Thirdly, there is a lack of labelling for construction materials with reused components in the market. One interviewee, the director of a construction waste recycling company, pointed out the immaturity of the construction waste recycling industry in China, indicating that “*the construction waste recycling business is kind of public welfare instead of profitable business*.” It has many risks, such as “*heavy regulations, high initial investment, sporadic supplies of recycled materials, immature market, less competitive product price, and other risk factors*”. The director regarded this kind of business “*the inherent responsibility of the government*”. Based on the feedback of several interviewees, the construction waste recycling industry in China remains stagnant due to the lack of sufficient policy and economic incentives.

The US Environmental Protection Agency (USEPA) interviewee referred to its program focusing on sustainable lifecycle management of various materials. In regard to end-of-life management of construction materials, the USEPA’s role includes providing technical assistance and tools to help US states manage and track amounts of construction materials within their jurisdictions; estimating the national amount of construction materials; and educating stakeholders about benefits of and best practices for using construction materials. As a result, the societal attitudes in the US have definitely become positive towards using recycled building materials.

Other issues shared by interviewees in relation to real-life projects should be noted. CWM-related credits evaluation is solely dependent on data and evidence submitted by the project applicant. For example, MR2 (Construction waste management) requires the recording of waste generated on site and calculation of the salvaged portion to indicate CWM performance. In China, specifications in a few major metropolitan areas, e.g., Beijing, Shanghai and Shenzhen, mandate proper waste management procedures, but there are no regulations specifying data collection on the amount of total construction waste and recycled/salvaged component. The data may often be imprecise and unreflective of the true construction waste minimization performance of the registered projects due to the lack of any verification process. In contrast, the treatment of waste is more formalized in the US. In Massachusetts, where most of this study’s American interviewees are based, the state government has some of the strictest regulations on waste management in the country, demanding on-site sorting, recycling, waste data recording and smart disposal. In 1990, the Massachusetts Department of Environmental Protection introduced its first waste ban regulations, prohibiting disposal of recyclable construction and demolition waste at solid waste facilities. According to several interviewees, these regulations are “*near-equivalent or tougher than LEED standards for achieving CWM-related credits*”. Therefore, the documentation process in accordance with LEED is generally rigorous.

There are other factors possibly contributing to the discrepancies in construction waste minimization performance which apply not just to specific credits but the whole process of applying the “green” concept to a project. In China, suggestions of green building consultants may be given low priority by project contractors. Also, LEED objectives may not be completely achieved because unskillful frontline workers cannot execute them. This problem seems to be especially prominent in the private sector. In the US, by contrast, project managers communicate well with green building consultants. Some interviewees indicated that some LEED objectives were incorporated into their contracts in the US to enforce compliance by project stakeholders to follow them.

Given the difficulties in obtaining CWM-related points, many green building consultants in China will try to obtain other easier LEED points instead of earning points under CWM-related credits at the beginning of a project. In other words, points under CWM-related credits are always regarded as a supplementary when the project is targeted to be awarded a silver certification or above. In this regard, platinum-level projects in the US and China consider get as much more points as possible even from CWM-related credits resulting in no difference in construction waste minimization performance between the two countries; however, when a project is at a low certification level, the CWM-related credits may not be regarded as the first priority to be obtained for China projects. This is one possible explanation to the discrepancies shown in the Table 5.

5. Discussion

Our statistical analyses reveal a difference in construction waste minimization scoring between LEED-certified projects in the US and China. At the platinum level, there is no significant difference. However, US projects perform better than those in China under the certification levels of gold, silver and certified, and the effect size increases when the certification level is lower. The analyses of interview data imply that the PEST profiles of the two contexts provide clues accounting for the differences. The detailed PEST profiles of construction waste minimization within the US and China are summarized in the Table 7.

From a political perspective, US waste management regulations are strict enough to fulfil LEED requirements. The USEPA regulates waste management with dedicated efforts from state, regional, and local entities. The USEPA Resource Conservation and Recovery Act (U.S. Code Title 42, Chapter 82, Sections 6901 et seq.) is a federal public law creating the framework for the proper ‘cradle-to-grave’ management of construction waste, while state regulations help to boost waste minimization. In China, development of construction waste minimization is rather low level overall and distinctively uneven across regions. There is no national law directly mandating proper management of construction waste, and the one relevant regulation entitled *Regulations on Urban Construction Waste Management* provides general and vague prohibitions. Only a few advanced cities, such as Shenzhen and Shanghai, have regional regulations and guidance stipulating appropriate waste treatment procedures. In many cities, a considerable amount of construction waste still ends up in landfills without proper source separation. Sakai et al. (2011) indicate that China may need to improve its ability to implement legislation to achieve better waste management outcomes. Laws and regulations can be one approach to promote or guarantee construction waste minimization performance, so that CWM-related credits are still obtained even when a project is granted with low certification level.

China’s rapid urbanization and urban renewal has led to a large volume of new building, demolition, or reconstruction projects. According to ex-Vice Minister of the Ministry of Construction, China, Qiu, 2010, new buildings are typically demolished after 25—30 years even though the designed service life is 50 years or more. Except for a few iconic buildings, most old buildings become dilapidated or are dismantled without consideration of reuse value (Liu et al., 2010). In these circumstances, it is difficult for projects to reach the LEED component reuse percentage thresholds. The US, in contrast, is a developed country facing fewer problems caused by ultra-urbanization due to an emphasis on building renovation and urban regeneration. Moreover, local market’s potential and constraints are one more concern affecting the adoption of recycled building products (Ismaeel, 2019). The infancy of China’s construction waste recycling market and uncompetitive price of eligible recycled building products have contributed to the divergence of construction waste minimization performance between China and the US (Couto and Couto, 2010; Lu et al., 2019). In

Table 7
PEST profiles for construction waste minimization (CWM) within the US and China.

PEST factors	US	China
Political	• At federal level, the *Resource Conservation and Recovery Act* (U.S. Code Title 42, Chapter 82, Sections 6901 et seq.) is the public law that creates the framework for the proper management of construction waste. • At regional level, there are around 17 regulations in Massachusetts mandating proper CWM procedures, e.g. 310 CMR *19.000: Solid Waste Facility Regulations.* • States', regional and local regulations are near equivalent with or tougher than LEED standards, such as creating a waste management plan and building specifications for managing CWM, source separation, e.g. asphalt, brick and concrete, steel, wood products, drywall and plaster, etc. (DEP, 2014). • Tax deductions are available when reusable materials are donated to nonprofit organizations	• At national level, there is no law directly mandating proper management of construction waste. • At regional level, there are some regulations mandating proper CWM procedures only in few advanced cities, e.g. *Regulations on Construction Waste Management in Shenzhen, Regulations on Disposal of Construction Waste in Shanghai.* • Lack of consolidated classification of construction waste, normally classified into hazardous/non-hazardous, dry/wet • Ambiguous standards for demolition/deconstruction work • Lack of political support in advocating the adoption of recycled construction materials • Lack of standards for necessary data collection and archiving.
Economic	• Urbanization rate is 82.30% in 2018 with an annual growth rate of 0.24% • Advocacy of sustainable urbanism under slowdown of urban expansion • A relatively limited volume of construction projects • Mature construction waste recycling industry structure	• Urbanization rate is 59.59% in 2018 with an annual growth rate of 1.06% • Huge amount of new construction projects under rapid urbanization • Immature market for a construction waste recycling industry • Limited economic incentives to adopt recycled construction materials
Social	• Positive societal attitudes towards using recycled building materials • Emphasis on old building renovation and urban regeneration • Effective communication with green building consultants • Preserving existing buildings rather than constructing new ones and optimizing the size of new buildings	• Poor public awareness of CWM • Poor appreciation of reuse value of old buildings • Distrust of the quality and durability of recycled material • The mindsets of "fond of the new and tired of the old", "new is better" and "the bigger, the better". • Inferior position of green building consultants in the construction industry
Technological	• More options of qualified building technologies • CWM treatment included in bid specifications • Consideration of a pre-demolition clean-out and some level of deconstruction rather than demolition	• Unskilled on-site workforce • Insufficient funds to support CWM research • Deficient standard operation procedures for demolition/deconstruction work

Data source: US Census Bureau, National Bureau of Statistics (NBS) of China.

summary, the highly developed construction waste recycling market in the US can guarantee a good construction waste minimization performance for all the green building projects; in China, there are large project volumes due to its fast-growing economy while the development of construction waste recycling industry cannot ensure all the projects perform well on construction waste minimization.

While the societal attitudes in the US are positive about the use of recycled building materials, Chinese society doubts the quality of "old things" (Couto and Couto, 2010; Lu et al., 2019). It is hard for Chinese project stakeholders to trust the quality of recycled materials (Yuan, 2013), and brand-new building materials are the first choice for Chinese contractors. More importantly, public awareness of construction waste minimization is relatively weak in China. Clients unfamiliar with best practices in construction and contractors uninterested in waste management are barriers to be responsible for construction waste minimization. Due to the efforts of public authorities in the US, attitude towards construction waste minimization are rather more positive, especially for frontline practitioners (e.g. on-site haulers). Therefore, unlike the US green building projects, CWM-related credits are always treated difficult to be obtained in China and they are regarded as supplementary credits in green building projects especially at low certification levels.

Off-site design and construction technologies such as prefabrication, unitization, and modularization are trusted in the US (NRC, 2009; Grosskopf et al., 2017). In China, the unskilled workforce, unregulated demolition/deconstruction work procedure, and rapid and rough construction management remain technical constraints for construction waste minimization (Lu and Tam, 2013; Poon et al., 2004; Tam and Tam, 2008; Wang et al., 2008). Technical factors increase the difficulties for construction waste minimization in China, green building projects in China may obtain other points than CWM-related credits when they do not need to be awarded with a platinum certification level.

6. Conclusion

This research compares construction waste minimization performance of green building projects in the US and China at four LEED certification levels. The Mann Whitney *U* and effect size tests found that at the LEED platinum level, there was no significant difference in the US and China construction waste minimization performance. However, the magnitude of the difference between the two countries increased with projects at lower certification levels.

We triangulated our quantitative results with interview data to understand the causes of this difference in construction waste minimization performance. We found that the differences in the PEST profiles of the two countries go a long way to explaining the performance disparity. A key factor is that the laws and regulations concerning construction waste minimization have not been well developed, particularly for enforcement, in China. Economic development in China has created a boom in construction projects, but the low reuse rate of construction components affects construction waste minimization performance in green building projects, especially projects with lower certification levels. The greater consciousness of "going green" in the US improves its overall construction waste minimization performance; while China is still catching up in this sustainable development cause, only a few projects with a higher green building certification level have the consciousness of increasing their construction waste minimization performance. From a technological perspective, construction technology in China has much space for enhancement to guarantee a better construction waste minimization performance. The influence of PEST profiles on construction waste minimization performance increased when the projects were certified with lower green building levels. The green building movement improves construction waste minimization performance and an amenable PEST context should be fostered to achieve better construction waste minimization performance and sustainability goals.

The research further emphasizes the significance of the context applying a sustainability assessment tool. A particular green building rating system should fully consider the laws and regulations within the context. Assessment tools should also be developed with the engagement of stakeholders. The local green building council can work with state and local officials, salvage and reuse outlets, contractors, waste processors and haulers, architects, and other stakeholders to develop consensus-based guidance. Integration between expert-led and citizen-led evaluation criteria make it possible to uncover region-specific and hidden local profiles, successful for measuring the performance of sustainability.

This research has its limitations. Firstly, the 599 US projects considered are only a sample of the 10,000+ LEED-certified projects in that country. It would have been too onerous to source detailed data on their construction waste minimization performance to pursue a full coverage of the projects. Secondly, it is recommended to compare the effects of LEED in economies other than the US and China under different PEST conditions. Thirdly, building performance under fields other than construction waste minimization, e.g. energy consumption, waste efficiency and indoor environment quality could be examined to discover the differences in various contexts.

CRediT author statement

Bin Chi: Conceptualization, Methodology, Data Curation, Investigation, Writing-Original draft, Writing - Review & Editing; **Weisheng Lu:** Conceptualization, Methodology, Supervision, Funding acquisition; **Meng Ye:** Methodology, Formal analysis, Investigation, Writing-Original draft, Writing - Review & Editing; **Zhikang Bao:** Conceptualization, Data Curation; **Xiaoling Zhang:** Writing - Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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