Evaluating LEED commercial interior (LEED-CI) projects under the LEED transition from v3 to v4: the differences between China and the US

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ABSTRACT

This study aims to assess the difference between projects from versions 3 (v3) and 4 (v4) of the Leadership in Energy and Environmental Design Commercial Interiors (LEED-CI) rating system in China and the US at the Silver and Gold certificate levels. Non-parametric statistics are used to estimate these differences. We analyze the Sustainable Sites (SS), Location and Transportation (LT), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), and Indoor Environmental Quality (EQ) categories for the LEED-CI Silver and Gold projects. The results show that the WE and EA categories in v3 and the WE, EA, LT, and MR categories in v4 are implemented differently in China and the US. For the LEED-CI Silver and Gold projects, the MR and EQ categories in v3 and the EQ category in v4 show similar implementation in China and the US. The LEED-CI v3 SS category shows a different result at the Gold level but the same at the Silver level when comparing China and the US. Thus, at the Silver and Gold levels of the LEED-CI projects, v4, rather than v3, provides more opportunities to highlight the environmental priorities of China and the US.

1. Introduction

The Leadership in Energy and Environmental Design (LEED) rating system was developed in the US in 1998 by the US Green Building Council (USGBC) (Ade and Rehm, 2020). LEED was designed for various types of buildings. These include the LEED for New Construction and Major Renovations (LEED-NC), Existing Buildings: Operations and Maintenance (LEED-EB), Core and Shell Development (LEED-C and S), and Commercial Interiors (LEED-CI), among others. Each of these schemes measures building sustainability according to the project performance for sustainable sites (SS)/location and transportation (LT), water efficiency (WE), the energy and atmosphere (EA), materials and resources (MR), the indoor environmental quality (EQ), the innovation and design process (ID), and regional priority (RP). All of the categories have one/several credits, with available points awarded according to the importance of these credits. Using the overall sum of the awarded points achieved by a project, a certain certification level is assigned by the USGBC, namely, either Certified (40–49 points), Silver (50–59 points), Gold (60–79 points), or Platinum (80 points and above).

After being developed in the US, the LEED rating system is now also issued in foreign countries, and, in this way, it has become an international certification system (Neama, 2012). In this respect, the LEED has been reported to be very widely used in Europe, especially in countries such as Italy, Turkey, Spain, Finland, and Sweden (Głuszak, 2015). Use of an international rating system in foreign countries requires maximal adaptation towards the local climate and resource availability, as well as the local technology, demographics, and cultural issues (Neama, 2012; Faulconbridge, 2015; Suzer, 2015). However, LEED is often criticized due to the fact that the scoring of credits does not take into account the importance of environmental resources and the needs of other countries (Suzer, 2015). In particular, Suzer (2015) noted that the necessity of providing a more flexible weighing system has already been recognized in LEEDv3, but this has not been implemented in LEEDv4. Other researchers, such as Faulconbridge (2015), have also noted that such an inflexible LEED format could make it impossible to build green buildings with appropriate environmental priorities for particular countries. Thus, the problem of the non-adaptation of the LEED system to the needs of foreign countries is well-known and highly discussed through the literature.

In this respect, LEED has tried to take into account the environmental priorities of countries other than the US by introducing some measures. In particular, versions 3 and 4 (v3 and v4, respectively) of the LEED system suggest the development of regional priority points and alternative compliance paths (Wu et al., 2018). LEED has four bonus RP points.

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When design teams perform a credit that corresponds to their country-specific environmental concern, they can be awarded the credit points and one of the RP points. Currently, the assignment of RP points to other foreign countries is performed by the USGBC. However, these measures have also been criticized.

According to Suzer (2015), foreign RP points usually cover common water and energy problems and do not reflect real local problems. Suzer (2015) conducted a qualitative analysis of the RPs of Canada, Turkey, China, and Egypt and revealed inconsistencies in the RPs suggested by the USGBC and the real local problems. For example, despite the fact that Turkey has a significant water shortage, its RPs do not include any water-saving credits. China, which is highly populated, did not have any city-relevant RP credits. Canada and Egypt were also found to have similar inconsistencies in their RPs and their actual country-specific problems (Suzer, 2015).

To verify this LEED criticism, it is necessary to study the empirical evidence of LEED foreign certification practices. Research in this area has recently emerged (Pushkar, 2018a, 2018b; Wu et al., 2018; Pham et al., 2020). Pushkar (2018a) compared LEED-NC v3 2009 Gold projects certified in two pairs of northern and southern European countries, namely, Finland versus Sweden and Turkey versus Spain. Different strategy patterns were revealed for these countries by the author. For example, for WEc1 (water efficient landscaping), Sweden's level of achievement was higher than Finland's, and Spain's level of achievement was higher than Turkey's. Similar differences in the countries' performances were also noticed in other categories, such as EA, MR, and EQ (Pushkar, 2018a).

Pushkar (2018b) performed an additional analysis of LEED-CI v3 and LEED-C and Sv3 Gold projects certified in three Mediterranean countries, namely, Turkey, Spain, and Italy. These countries have similar regional environmental concerns. Pushkar (2018b) reported on the similar high SS performance, the similar low MR performance, and the similar intermediate EQ performance, whereas the WE and EA performed differently despite the similar high level of water stress experienced by these Mediterranean basin countries.

Wu et al. (2018) compared LEED-NC v3 certified projects in the US, China, Turkey, and Brazil. RPs and 21 regionally specific credits with alternative compliance paths were analyzed. The authors confirmed the presence of unbalanced achievements in the RPs of these countries. However, different country-relevant strategies for 21 regionally specific credits were found by Wu et al. (2018). The most prominent differences were reported for the US and China (countries with completely different political, economic, social, and technological contexts), where the US had better achievement in the EA category and China performed better in the SS and WE categories (Wu et al., 2018).

Pham et al. (2020) studied LEED-NC v3 Silver, Gold, and Platinum projects certified in the southern part of Vietnam. This area features a humid, tropical climate. The results showed that most of the SS, WE, and EQ credits were achieved at a high standard in this country. The authors concluded that the revealed LEED awarding strategy reflected specific characteristics of Vietnam and can serve as basis for future development of the Vietnamese green regulations.

Empirical evidence of the LEED certification contradicts the above-mentioned criticism of the inability of LEED to give a sufficient framework for developing sustainable buildings in foreign countries. However, all of these empirical studies have focused only on one LEED version and, therefore, these studies lack an evaluation of the evolutionary dynamics of LEED certification moving from version to version. Moreover, specific information on LEED buildings at the country level is needed. Without a thorough understanding of the strategies required to achieve preferred categories or credits, potential owners may not be aware of the advantages and disadvantages of the LEED building they want to purchase (Reed et al., 2009).

Thus, this study seeks to fill this gap by expanding the following question about foreign LEED certification: In practice, how did improving LEED-CI from v3 to v4 affect the environmental expectations of potential owners in China and the US? To answer this question, we compared the China-LEED-CI and the US-LEED-CI projects for v3 and v4 at Silver and Gold levels.

The US was chosen as one of the original countries for which LEED was developed, and China was chosen as a foreign country which also uses the LEED for green certification. It was supposed that comparing LEED certifications in these two completely different countries with different economic, social, and technological contexts (Chi et al., 2020) might lead to the identification of sharp differences in the US and China LEED-CI v3 and LEED-CI v4 certification strategies.

The main contribution of this comparative country-specific study is the disclosure of reliable information about preferred strategies used for category and credit achievements in China and the US. This information could be useful for LEED developers, who are aiming to design a flexible credit weighting system to improve the adaptation of LEED to the environmental needs of different countries (Suzer, 2015). In addition, China city-specific and US state-specific information about the environmental improvements of their Silver and Gold LEED-CI v3 and 4 projects could be useful for potential building owners or occupants. This is because such knowledge helps to identify the sustainable advantages of owning an LEED building (Reed et al., 2009).

2. Methods

2.1. Design of the study

In order to compare v4 with v3 for LEED-CI certification projects in two different countries, it was necessary for these projects to belong to one rating system, one certification level, one geographical location and, if possible, one previously certified date (Pushkar, 2018c; Pushkar and Verbitsky, 2018, 2019a, 2019b). Under these conditions, only LEED-CI v4 and LEED-CI v3 at the Silver and Gold certification levels in China and the US had acceptable sample sizes to allow a reliable statistical analysis to be conducted according to the USGBC based on information from January 1, 2020 (USGBC).

At this time, in China, there were 8 LEED-CI v4 Platinum and 4 Certified projects, and, in the US, there were 5 LEED-CI v4 Platinum and 63 Certified projects. Due to the small number of projects at the Platinum level or those that were not equal at the Certified level (as of January 1, 2020, https://www.usgbc.org/projects), we did not perform statistical analysis at these levels. This conclusion is based on the Mundry and Fischer (1998) study, who noted, in a non-experimental study, that the minimal sample size for the Wilcoxon–Mann–Whitney (WMW) test is as follows: If $n_1 = 5$ then $n_2 > 10$. The spatial-temporal characteristics of the LEED-CI certified projects in China and the US are shown in Table 1.

To match the observations, the number of v3 projects was determined by the number of v4 projects. In China, the v3 projects were from the same city and similar last certified data were used for the projects. In the US, the v3 projects were from the same state and similar last certified data were used for the projects (USGBC).

Based on the USGBC database (as of January 1, 2020, https://www.usgbc.org/projects), we selected the administrative-climatic sampling frame at the city level in China and at the state level in the US. This can be illustrated by the following example: For LEED-CI v4 Gold projects, 66% of the Chinese projects are located in Shanghai, and 31% of the US projects are located in California. These California LEED-CI v4 Gold projects are distributed in the following six cities, where the numbers in brackets represent the numbers of projects: San Francisco (4), Santa Monica (1), Sunnyvale (2), Los Angeles (2), San Diego (1), and Menlo Park (1). In this context, we suggest that the difference between states in the US and the difference between cities in China is much smaller than the difference between China and the US. Recently, Chi et al. (2020) used a similar comparison between China and the US where the performance of the LEED-Nc v3 construction waste minimization credits was analyzed.

Thus, for these China and the US project locations, information regarding awarded points in the SS/LT, WE, EA, MR, and EQ categories of
Table 1. Spatio-temporal characteristics of Leadership in Energy and Environmental Design Commercial Interiors (LEED-CI) certified projects in China and the US.

| Region | China, LEED-CI Gold certification | China, LEED-CI Silver certification |
|--------|----------------------------------|------------------------------------|
| Version 4 | Version 3 | Version 4 | Version 5 |
| Shanghai (25) 2015–2019 | Shanghai (25) 2015–2018 | Shanghai (7) 2017–2019 | Shanghai (7) 2010–2017 |
| Beijing (9) 2014–2018 | Beijing (9) 2016–2018 | Beijing (6) 2017–2019 | Beijing (6) 2011–2015 |
| Chengdu (2) 2019 | Chengdu (2) 2015–2018 | Guangzhou (2) 2018–2019 | Guangzhou (2) 2016–2017 |
| Guangzhou (1) 2019 | Guangzhou (1) 2017 | Shenzhen (1) 2019 | Shenzhen (1) 2011 |
| Hangzhou (1) 2018 | Hangzhou (1) 2016 | | |
| Total (38) | Total (38) | Total (37) | Total (37) |

| Region | US, LEED-CI Gold certification | US, LEED-CI Silver certification |
|--------|----------------------------------|--------------------------------|
| Version 4 | Version 3 | Version 4 | Version 5 |
| CA (11) 2015–2019 | CA (11) 2015–2018 | CA (13) 2018–2019 | CA (13) 2018–2019 |
| NY (4) 2018–2019 | NY (4) 2018–2019 | IL (5) 2017–2019 | IL (5) 2017–2019 |
| MA (4) 2018–2019 | MA (4) 2018–2019 | NY (4) 2016–2019 | NY (4) 2016–2018 |
| WA (3) 2018–2019 | WA (3) 2014–2019 | TN (3) 2019 | TN (3) 2016–2019 |
| IL (3) 2018 | IL (3) 2018–2019 | MA (2) 2018–2019 | MA (2) 2018–2019 |
| VA (2) 2019 | VA (2) 2018 | FL (2) 2019 | FL (2) 2019 |
| CO (2) 2017–2019 | CO (2) 2017–2019 | CO (1) 2017 | CO (1) 2017 |
| NJ (2) 2018–2019 | NJ (2) 2018 | PA (1) 2019 | PA (1) 2019 |
| TX (2) 2019 | TX (2) 2017–2019 | NM (1) 2018 | NM (1) 2018 |
| NC (1) 2019 | NC (1) 2019 | MD (1) 2018 | MD (1) 2018 |
| MD (1) 2019 | MD (1) 2019 | MI (1) 2018 | MI (1) 2018 |
| FL (1) 2019 | FL (1) 2019 | DC (1) 2019 | DC (1) 2018 |
| Total (36) | Total (36) | OH (1) 2019 | OH (1) |

Notes: Numbers in parentheses denote the number of projects.

CA: California; CO: Colorado; DC: District of Columbia; FL: Florida; GA: Georgia; IL: Illinois; MA: Massachusetts; MD: Maryland; MI: Michigan; MN: Minnesota; MO: Missouri; NC: North Carolina; NJ: New Jersey; NM: New Mexico; NY: Nevada; NY: New York; OH: Ohio; OR: Oregon; PA: Pennsylvania; TN: Tennessee; TX: Texas; VA: Virginia; VT: Vermont; WA: Washington.

LEED-CIv4 and LEED-CIv3 Silver and Gold certifications was downloaded from the USGBC projects site (https://www.usgbc.org/projects) and recorded in Excel format for further statistical analysis.

2.2. Statistical analysis

2.2.1. Selecting an appropriate statistical test

For descriptive statistics, we used the median and first and third quartiles (25th and 75th percentiles) instead of the mean ± standard deviation, as the LEED data are associated with an ordinal scale. For inferential statistics, the non-parametric Cliff’s δ effect size test and the exact Wilcoxon–Mann–Whitney (WMW) nonparametric test were used instead of the parametric Cohen's d test and the parametric Student's t-test, respectively, because “…the original measurements were made on an original scale” (Bergmann et al., 2000) and the assumption of normality for the LEED data was not met. According to Bergmann et al. (2000), the exact WMW nonparametric test should be used instead of the asymptotic approximation WMW test, because the LEED dataset contains the same values or “tied data” (Bergmann et al., 2000).

According to Cliff (1993), the δ test measures the difference in the magnitude between two distributions, and, according to Bergmann et al. (2000), the WMW procedure tests for the equality of group mean ranks but not group medians. Recently, Chi et al. (2020) used both Cliff’s δ effect size test and the WMW test to evaluate the difference between China-LEED and the US-LEED New Construction v3 certified projects in terms of construction waste minimization.

2.2.2. Cliff’s δ effect size test

We used Cliff’s δ to measure the substantive significance (effect size) between two unpaired groups. Cliff’s δ (Cliff, 1993, p. 495) is expressed as follows (see Eq. (1)):

δ = #{x1 > x2} - #{x1 < x2}(n1n2) (1)

where x₁ and x₂ are the scores within group 1 and group 2, respectively, n₁ and n₂ are the sizes of the sample groups, group 1 and group 2, respectively, and # indicates the number of times.

Cliff’s δ ranges between -1 and +1. Positive (+) values indicate that group 1 is larger than group 2, 0 indicates equality or overlap, and negative (-) values indicate that group 2 is larger than group 1 (Cliff, 1993).

According to Romano et al. (2006), the effect size is considered to be (i) negligible if |δ| < 0.147, (ii) small if 0.147 ≤ |δ| < 0.33, (iii) medium if 0.33 ≤ |δ| < 0.474, and (iv) large if |δ| ≥ 0.474. According to Cohen (1992), a medium effect is “visible to the naked eye of a careful observer.” A low effect is “noticeably smaller than medium but not so small as to be trivial.” A high effect is “the same distance above the medium as small is below it.” It should be noted that the effect size is not part of an “iron-clad criteria” (Durlak, 2009), but only a general rule of thumb that might be followed in the absence of knowledge (Volker, 2006).

2.2.3. Statistical analysis of binary data

To evaluate the effect size and the statistical significance between two LEED binary (“0 or 1”) credits, we used the natural logarithm of the odds ratio (lnθ) instead of Cliff’s δ and Fisher's exact 2 × 2 test with a two-tailed Lancaster's mid-P-value instead of the WMW test, respectively. According to Haddock et al. (1998), if lnθ or the Log Odds Ratio is 0, then there is no association between the LEED points and China/the US. The left and right limits of lnθ are infinity (the function can change infinitely in either direction away from zero) (Haddock et al., 1998). Consequently, a value of lnθ moving away from zero reflects a stronger relationship between the LEED credit and China/the US. The degree of association...
between binary outcomes was adapted from the study by Chen et al. (2010). The effect size thresholds of the absolute lnθ lnθ were 0.51 (small), 1.24 (medium), and 1.90 (large).

2.2.4. P-value interpretation

In the current study, we used neo-Fisherian significance assessments (NFSAs) instead of the Paleo-Fisherian and Neyman–Pearson paradigms (i.e., null hypothesis significance tests (NHST)) (Hurlbert and Lombardi, 2009). According to Hurlbert and Lombardi (2009), the NFSA paradigm includes the following definitions: (1) The paradigm does not fix α (i.e., the level of significance). (2) The paradigm does not describe F-values as “significant” or “nonsignificant.” (3) The paradigm does not accept null hypotheses based on high P-values but only suspends judgment. (4) The paradigm interprets significance tests according to “three-valued logic.” Finally, (5) the paradigm presents effect size information in conjunction with significance tests. Additionally, Hurlbert and Lombardi (2009) cited the recommendation of Gotelli and Ellison (2004), noting that “in many cases, it may be more important to report the exact P-value and let the readers decide for themselves how important the results are.” According to Beninger et al. (2012), the logic of Occam’s mechanical razor should not be used for universal interpretation of the P-value.

Hurlbert and Lombardi (2009) clearly showed that fixing α, i.e., the level of significance (e.g., α = 0.05), and dichotomizing the scale of the P-values, i.e., P ≤ α or P > α, are superfluous. Hurlbert and Lombardi (2009, p. 316) cited Fischer’s philosophical proposal that “no scientific worker has a fixed level of significance at which from year to year, and in all circumstances, he rejects [null] hypotheses; he rather gives his mind to each particular case in light of his evidence and ideas.” (Fisher, 1956). In addition, Hurlbert and Lombardi (2009, p. 317) cited Altman (1991), who noted “It is ridiculous to interpret the results of a study differently according to whether the P value obtained was, say, 0.055 or 0.045. These P values should lead to very similar conclusions, not diametrically opposed ones.” Therefore, NFSAs include calculations of both the exact P-value and the effect size, but there is no need to specify α.

Following Hurlbert and Lombardi (2009), the P-values were evaluated according to three-valued logic, namely, either it seems to be positive (i.e., there seems to be a difference between China and the US), it seems to be negative (i.e., null hypothesis seems to be nonsignificant) or judgment is suspended (regarding the difference between China and the US).

3. Analysis studies

3.1. LEED certification

Table 2 shows descriptive and inferential statistics for the total achieved points in the LEED-CI v3 and v4 projects. The results of the LEED-CIv3 Silver and Gold projects in both China and the US were similar and the differences between China and the US seemed to be negative. In contrast, the results of the LEED-CIv4 Silver and Gold projects in China and the US were different: China showed better results than the US and the differences between China and the US seemed to be positive.

3.2. LEED categories

Table 3 demonstrates descriptive and inferential statistics for the LEED-CI v3 and v4 Silver and Gold projects at the category level. In general, China was found to have a high level of achievement in the IP, SS, LT, WE, and RP categories, whereas the US had a high level of achievement in the EA and MR categories. Moreover, the number of differently performing categories increased as the certified projects moved from Silver to Gold and from LEED-CIv3 to LEEDv4. Moreover, (i) for the Gold projects, the number of differently performed categories was higher than for the Silver projects and (ii) the number of differently performed categories was greater for the LEED-CIv4 projects than for the LEED-CIv3 projects.

In particular, for the LEED-CIv3 Silver projects, China emphasized the WE category and the difference between China and the US seemed to be positive. For the LEED-CIv3 Gold projects, the SS, WE, and RP categories showed better results in China than in the US, whereas the EA category showed better results in the US than in China. In all these categories, the differences between China and the US seemed to be positive.

According to the results of the LEED-CIv4 Silver projects, the LT and WE categories showed better results in China than in the US, whereas the EA category showed better results in the US than in China. For all of these categories, the differences between China and the US seemed to be positive. For the LEED-CIv4 Gold projects, the IP, LT, and WE categories showed better results in China than in the US, whereas the EA and MR categories showed better results in the US than in China. In all these categories, the differences between China and the US seemed to be positive.

No clear tendency was noticed for the RP category: For the Gold LEED-CIv3, China performed better than the US and the differences between China and the US seemed to be positive, whereas for the Silver LEED-CIv4, the US performed better than China and the judgment relating to differences between China and the US was suspended. The EQ and IN categories performed similarly in both countries for the LEED-CI v3 and v4 Silver and Gold projects.

3.3. LEED credits

3.3.1. Sustainable site and location and transportation

Table 4 shows the descriptive and inferential statistics for the SS and LT credits of the LEED-CI v3 and v4 Silver and Gold projects. For the LEED-CIv3 Gold SS credits, only “SSc3.3, alternative transportation—parking availability” showed better results in China than in the US and the difference between China and the US seemed to be positive, whereas the LEED-CIv4 Silver and Gold LT credits, “LTc2, surrounding density and diverse uses”, “LTc3, access to quality transit”, and “LTc5, reduced parking footprint” showed better results in China than in the US and the differences between China and the US seemed to be positive.

3.3.2. Energy and atmosphere

Table 5 demonstrates the descriptive and inferential statistics for the EA credits of the LEED-CI v3 and v4 Silver and Gold projects. For the
LEED-CIv3 Silver EA credits, “EAc1.1, optimized energy performance—lighting power” showed better results in the US than in China and the differences between China and the US seemed to be positive. For the LEED-CIv3 Gold EA credits, “EAc2, enhanced commissioning” and “EAc4, green power” showed better results in the US than in China, whereas “EAc3, measurement and verification” showed better results in China than in the US. For all of these credits, the differences between China and the US seemed to be positive.

For the LEED-CIv4 Silver EA credits, “EAc4, enhanced refrigerant management” demonstrated better results in China than in the US, whereas “EAc5, green power and carbon offsets” showed better results in the US than in China and the difference between China and the US seemed to be positive. For the LEED-CIv4 Gold EA credits, “EAc1, enhanced commissioning”, “EAc3, renewable energy production”, “EAc5, green power and carbon offsets”, and “EAc6, optimize energy performance” showed better results in the US than in China, whereas “EAc4, enhanced refrigerant management” showed better results in China than in the US. For all of these comparisons, the difference between China and the US seemed to be positive.

3.3.3. Material and resources

Table 6 shows the descriptive and inferential statistics for the MR credits of the LEED-CI v3 and v4 Silver and Gold projects. With the LEED-CIv3 Silver MR credits, “MRc1.1, tenant space—long-term commitment” showed better results in the US than in China, and the difference between China and the US seemed to be positive. For the LEED-CIv3 Gold MR credits, “MRc1.1 showed better results in the US than in China, whereas “MRc5, regional materials” showed better results in China than in the US. For both these credits, the difference between China and the US seemed to be positive. Additionally, “MRc7, certified wood” showed better results in the US (five of the total 36 projects achieved this credit) than in China (none of the 38 projects achieved this credit) and the difference between China and the US seemed to be positive.

With the LEED-CIv4 Silver and Gold MR credits, “MRc1, long-term commitment”, “MRc3, building product disclosure and optimization (BPD and O)—environmental product declarations”, “MRc4, BPD and O—sourcing of raw materials”, and “MRc5, BPD and O—material ingredients” showed better results in the US than in China and the differences between China and the US seemed to be positive for all these credits. For the LEED-CIv4 Gold MR credits, “MRc6, construction and demolition waste management” showed better results in China than the US and the differences between China and the US seemed to be positive.

3.3.4. Indoor environmental quality

Table 7 shows the descriptive and inferential statistics for the EQ credits of the LEED-CI v3 and v4 Silver and Gold projects. For the EQ
Table 4. The LEED-CI v3 and v4 projects: Sustainable site (SS) and location and transportation (LT) credits.

| Credit                                                                 | Level    | Pt  | Median and 25th-75th centiles | δ/ln(θ) | P     |
|------------------------------------------------------------------------|----------|-----|-------------------------------|---------|-------|
| **LEED-CIv3**                                                          |          |     |                               |         |       |
| SSc1 Site selection                                                   | Silver   | 5   | 1.0 1.0-2.0                   | 0.0001  | 0.0961|
|                                                                        | Gold     | 3.0 | 3.0 2.0-5.0                   | -0.09   | 0.4896|
| SSc2 Development density and community connectivity                    | Silver   | 6   | 6.0 6.0-6.0                   | 0.08    | 0.2203|
|                                                                        | Gold     | 6.0 | 6.0 6.0-6.0                   | 0.08    | 0.2203|
| SSc3.1 Alternative transportation—public transportation access        | Silver   | 6   | 6.0 6.0-6.0                   | 0.14    | 0.3058|
|                                                                        | Gold     | 6.0 | 6.0 6.0-6.0                   | 0.08    | 0.2203|
| SSc3.2 Alternative transportation—bicycle storage and changing rooms   | Silver   | 2   | 0.0 0.0-0.0                   | 0.15    | 0.4298|
|                                                                        | Gold     | 0.0 | 0.0 0.0-0.0                   | 0.07    | 0.6737|
| SSc3.3 Alternative transportation—parking availability                | Silver   | 2   | 2.0 2.0-2.0                   | 0.28    | 0.1115|
|                                                                        | Gold     | 2.0 | 2.0 2.0-2.0                   | 0.58    | 0.0001|
| **LEED-CIv4**                                                          |          |     |                               |         |       |
| LTC2 Surrounding density and diverse uses                              | Silver   | 8   | 8.0 8.0-8.0                   | 0.35    | 0.0085|
|                                                                        | Gold     | 8.0 | 8.0 8.0-8.0                   | 0.26    | 0.0028|
| LTC3 Access to quality transit                                         | Silver   | 7   | 7.0 7.0-7.0                   | 0.57    | 0.0001|
|                                                                        | Gold     | 7.0 | 7.0 7.0-7.0                   | 0.31    | 0.0004|
| LTC4 Bicycle facilities\(^1\)                                         | Silver   | 1   | 0.0 0.0-0.5                   | -0.24   | 0.8755|
|                                                                        | Gold     | 0.0 | 0.0 0.0-1.0                   | 0.59    | 0.2000|
| LTC5 Reduced parking footprint                                         | Silver   | 2   | 2.0 2.0-2.0                   | 0.58    | 0.0001|
|                                                                        | Gold     | 2.0 | 2.0 2.0-2.0                   | 0.33    | 0.0009|

Notes: The P-values were evaluated according to the following three-valued logic: Bold font—seems to be positive, ordinal font size—seems to be negative, and italic font—judgment is suspended.

\(^1\) To estimate the effect size and statistical difference between China and the US, the LEED-CIv4 LTC4 credit was treated using the Log Odds Ratio and Fisher's exact test 2 x 2 table with a two-tailed mid-P-value, respectively.

credits, the number of differences between China and the US decreased when the certification switched from version 3 to 4. For the LEED-CIv3 Silver EQ credits, “EQc2, increased ventilation” and “EQc8.1, daylight and views—daylight” showed better results in China than in the US, whereas “EQc4.3, low-emitting materials—flooring systems”, “EQc4.4, low-emitting materials—composite wood and agrifiber products”, and “EQc6.1, controllability of systems—lighting” showed better results in the US than in China. For all of these credits, the differences between China and the US seemed to be positive. It should be noted that, in the US, EQc4.4 was achieved in 15 of the 22 projects, whereas, in China, none of the 16 projects achieved this credit.

For the LEED-CIv3 Gold EQ credits, “EQc2, increased ventilation”, “EQc3.2, construction indoor air quality (IAQ) management plan—before occupancy”, “EQc7.2, thermal comfort—verification”, and “EQc8.1, daylight and views—daylight” showed better results in China than in the US, whereas “EQc4.3, low-emitting materials—flooring systems, “EQc4.4, low-emitting materials—composite wood and agrifiber products”, and “EQc4.5, low-emitting materials—systems furniture and seating” showed better results in the US than in China. For all of these credits, the differences between China and the US seemed to be positive.

For the LEED-CIv4 Silver EQ credits, “EQc4, indoor air quality assessment” showed better results in China than in the US and the differences between China and the US seemed to be positive. For the LEED-CIv4 Gold EQ credits, “EQc1, enhanced indoor air quality strategies”, “EQc5, thermal comfort”, and “EQc7, daylight” showed better results in China than in the US and the differences between China and the US seemed to be positive.

4. Findings and discussion

4.1. LEED certification and categories

The LEED-CIv3 Silver and Gold projects were found to have similar achievements in China and the US, whereas the LEED-CIv4 Silver and Gold projects showed greater achievement in China (53 and 64 achieved points in Silver and Gold projects, respectively) than in the US (52 and 63 achieved points, respectively). This was caused by the different emphasis on categories in China and the US (Table 3).

In particular, the LEED-CIv3 SS category and the LEED-CIv4 LT category performed better in China’s projects than in projects in the US (Table 3). Wu et al. (2018) also showed that the LEED-NCv3 SS category was implemented better in China than in the US.

In addition, China’s projects revealed the uniformly high performance of the WE category (especially for LEED-CIv3 Gold projects, in which all of the projects received a maximum of 11 points) (Table 3). According to Zhao et al. (2015), most Chinese provinces (17 of 30) experience moderate/severe water stress, six provinces experience extreme water stress, and only seven provinces experience no water stress. The projects analyzed in this study were located in northern China (Beijing) and eastern China (Shanghai), which experience extreme water stress (100% of water needs relative to the renewable fresh water sources) and in south-eastern China (Shanghai), which experience extreme water stress (100% of water needs relative to the renewable fresh water sources). Thus, the high performance of the WE category was expected for these water-stressed China provinces.

In this respect, it should be noted that the US also experiences water stress, which can be even greater than China's water stress (Smakhtin et al., 2004). However, the high levels of water stress in the US mainly occur in the southwestern states. In this study, only three analyzed states (IL, NY, and MA, among others) were in areas of low water stress (https://www.globalchange.gov/browse/multimedia/water-stress-us). Therefore, water-saving strategies are not a high priority in most of the analyzed states of the US, leading to lower WE category performance in the US projects compared to China’s projects.

Moreover, it should be noted that the studied projects were mostly located in Shanghai (a megacity in China with 24.15 million permanent residents [Gu et al., 2020]) and in California (the US state with the strongest local green policy [Greer et al., 2019]). In this respect,
Shanghai is recognized as a high purchaser of water-consuming goods produced in other provinces. Shanghai consumes 79% of the virtual water from these provinces (Zhao et al., 2016). Nevertheless, this megacity is still under high water stress, and its water-saving practices are also influenced its building sector.

As for California, its water saving practices are prescribed by California Green Building Standards Code (California Code of Regulation, Title 24, Section 4.3 Water efficiency and conservation [CGBSC, 2016]). The CGBSC requirement for water saving corresponds to LEED-CI v3 and v4 WE prerequisite requirements, which states that consumption should be 20% below the calculated baseline (Greer et al., 2019). In this study, in the WE category, the US was awarded 6 points for a design that consumes 35% below the calculated baseline. This is very similar to the CGBSC requirements.

Similar results for the WE category were also reported by Wu et al. (2018), who analyzed 4021 Silver and Gold projects certified under LEED-NCv3 in the US, China, Turkey, and Brazil and concluded that, in the WE category, China performs significantly better than the US.

However, the EA category was found to be better implemented in the US than in China. A high realization of the EA category in the US is concerned with green wind-based electricity. Nevertheless, in practical application, this scheme has not been successful because of the high prices associated with wind-based electricity and the lack of knowledge about the sustainability of green electricity (Hast et al., 2015).

Similar results were confirmed for LEED-NCv3 projects by Wu et al. (2018), who showed that the EA category has been implemented better in the US than in China. A high realization of the EA category in the US LEED-CIv4 projects, which increased from level to level, was also previously reported by Pushkar (2020) with the following median ± interquartile ranges (IQR; 25th–75th percentiles) for the achieved points: 12.0 ± 4.0, 14.0 ± 7.5, 22.5 ± 13.0, and 31.5 ± 7.5 for Certified, Silver, Gold, and Platinum projects, respectively.

Moreover, a similar low implementation of the MR category was evaluated in both China and the US for the LEED-CIv3 Silver and Gold projects, whereas the US projects were better implemented than China's projects in both the LEED-CIv4 Silver and Gold MR categories (Table 3). The low implementation of the MR category was also revealed in other countries. Pushkar (2018b) studied LEED-CIv3 Gold projects in Turkey, Spain, and Italy and reported their MR achievements as follows (median ± IQR): 2.0 ± 2.0, 3.0 ± 5.0, and 3.0 ± 2.5 awarded points, respectively. Pushkar and Verbitsky (2019b) studied LEED-CIv3 Silver and Gold certification projects in 14 US states (CA, CO, FL, GA, IL, MD, MA, NJ, NY, NC, OH, PA, TX, and WA) and also confirmed the presence of low MR achievements in these states (median ± IQR): 3.0 ± 3.0 and 6.0 ± 2.0 awarded points (the lowest in CO and the highest in PA).
Table 6. The LEED-CI v3 and v4 projects: Materials and resources (MR) credits.

| Credit | Level | Pt | Median and 25th–75th centiles | 1/ln | P |
|--------|-------|----|-------------------------------|------|---|
| MRc1.1 Tenant space—long-term commitment | Silver | 1 | 0.0–0.5, 1.0–1.0 | -1.83 | 0.0044 |
| | Gold | | 0.0–1.0, 1.0–1.0 | -2.26 | 0.0001 |
| MRc1.2 Building reuse—maintain interior constr. elements | Silver | 2 | 0.0–0.0, 0.0–0.0 | 0.04 | 0.9600 |
| | Gold | | 0.0–0.0, 0.0–0.0 | -0.03 | 0.9589 |
| MRc2 Construction waste management | Silver | 2 | 2.0–2.0, 2.0–2.0 | -0.04 | 0.8980 |
| | Gold | | 2.0–2.0, 2.0–2.0 | 0.11 | 0.3461 |
| MRc3.1 Materials reuse | Silver | 2 | 0.0–0.0, 0.0–0.0 | -0.05 | 0.9666 |
| | Gold | | 0.0–0.0, 0.0–0.0 | -0.03 | 0.9730 |
| MRc3.2 Materials reuse—furniture and furnishings | Silver | 1 | 0.0–0.5, 0.0–0.0 | 1.01 | 0.1561 |
| | Gold | | 0.0–0.0, 0.0–0.0 | 1.42 | 0.2760 |
| MRc4 Recycled content | Silver | 2 | 1.0–2.0, 1.0–2.0 | 0.01 | 0.9531 |
| | Gold | | 1.0–2.0, 1.0–2.0 | 0.11 | 0.4125 |
| MRc5 Regional materials | Silver | 2 | 1.0–2.0, 0.0–1.0 | 0.27 | 0.0970 |
| | Gold | | 1.0–2.0, 0.0–1.0 | 0.44 | 0.0004 |
| MRc6 Rapidly renewable materials | Silver | 1 | 0.0–0.0, 0.0–0.0 | NaN | 0.5000 |
| | Gold | | 0.0–0.0, 0.0–0.0 | -0.78 | 0.4249 |
| MRc7 Certified wood | Silver | 1 | 0.0–0.0, 0.0–0.0 | -inf | 0.1108 |
| | Gold | | 0.0–0.0, 0.0–0.0 | -inf | 0.0117 |

Notes: The P-values were evaluated according to the following three-valued logic: Bold font—seems to be positive, ordinal font size—seems to be negative, and italic font—judgment is suspended.

BPD and O—building product disclosure and optimization.
1 To estimate the effect size and statistical difference between China and the US, the LEED-CI v3 MRc1.1, MRc3.2 MRc6, and MRc7 credits and the LEED-CIv4 MRc1 credit were treated using the Log Odds Ratio and Fisher's exact test 2 × 2 tables with a two-tailed mid-P-value, respectively.

4.2. LEED credits

As was revealed in this study, the SS/LT credits perform better in China than in the US (Table 4). This is consistent with the results of Suzer (2015), who noticed that SS/LT is an important category for the highly urban population of China, as it concerns the restriction of virgin land development and transport-related greenhouse gas emissions. In particular, as was mentioned earlier, most of the studied projects were located in Shanghai, in which private car ownership is restricted and land development and transport-related greenhouse gas emissions. In this respect, as was speculated by Pushkar and Verbitsky (2018), the high US performance of this credit can be associated with one of the main energy regulations in the US, namely, ASHRAE 90.1 (Energy Standard for
### Table 7. The LEED-CI v3 and v4 projects: Indoor environmental quality (EQ) credits.

| Credit | Level | Pt | Median and 25th-75th centiles | s/ln(0) | P |
|--------|-------|----|--------------------------------|--------|----|
|        |       |    | China                          | US     |    |
| LEED-CIv3 |       |    |                                |        |    |
| EQc1 Outdoor air delivery monitoring | Silver | 1 | 0.0 0.0–0.0 | 0.0 0.0–0.0 | -0.18 | 0.8582 |
|         | Gold  |    | 0.0 0.0–1.0 | 0.0 0.0–1.0 | -0.55 | 0.2882 |
| EQc2 Increased ventilation | Silver | 1 | 1.0 0.5–1.0 | 0.0 0.5–1.0 | 2.23  | 0.0005 |
|         | Gold  |    | 1.0 1.0–1.0 | 0.0 1.0–1.0 | 1.39  | 0.0064 |
| EQc3.1 Construction IAQ manag. plan—during construct. | Silver | 1 | 1.0 1.0–1.0 | 1.0 1.0–1.0 | -0.16 | 0.8273 |
|         | Gold  |    | 1.0 1.0–1.0 | 1.0 1.0–1.0 | -0.19 | 0.8662 |
| EQc3.2 Construction IAQ manag. plan - before occupancy | Silver | 1 | 0.5 0.0–0.0 | 0.0 0.0–0.0 | 1.46  | 0.0326 |
|         | Gold  |    | 1.0 0.0–0.0 | 0.0 0.0–0.5 | 1.53  | 0.0017 |
| EQc4.1 Low-emitting materials—adhesives and seal. | Silver | 1 | 1.0 1.0–1.0 | 1.0 1.0–1.0 | -0.39 | 0.5475 |
|         | Gold  |    | 1.0 0.0–0.0 | 1.0 1.0–1.0 | -0.52 | 0.3518 |
| EQc4.2 Low-emitting materials—paints and coatings | Silver | 1 | 1.0 1.0–1.0 | 1.0 1.0–1.0 | -0.15 | 0.7725 |
|         | Gold  |    | 1.0 1.0–1.0 | 1.0 1.0–1.0 | 0.06  | 0.8075 |
| EQc4.3 Low-emitting materials—flooring systems | Silver | 1 | 0.0 0.0–0.0 | 1.0 0.7–1.0 | -2.60 | 0.0001 |
|         | Gold  |    | 0.0 0.0–1.0 | 1.0 1.0–1.0 | -2.62 | 0.0001 |
| EQc4.4 Low-emitting materials—composite wood | Silver | 1 | 0.0 0.0–0.0 | 0.0 0.0–1.0 | Inf   | 0.0013 |
|         | Gold  |    | 0.0 0.0–0.0 | 1.0 0.0–1.0 | -3.85 | 0.0001 |
| EQc4.5 Low-emitting materials—systems furniture | Silver | 1 | 0.0 0.0–1.0 | 0.0 0.0–1.0 | -0.63 | 0.3004 |
|         | Gold  |    | 0.0 0.0–1.0 | 1.0 0.0–1.0 | -1.11 | 0.0288 |
| EQc5 Indoor chemical and pollutant source control | Silver | 1 | 0.0 0.0–0.0 | 0.0 0.0–1.0 | -1.21 | 0.1362 |
|         | Gold  |    | 0.0 0.0–0.0 | 0.0 0.0–1.0 | -0.60 | 0.2597 |
| EQc6.1 Controllability of systems—lighting | Silver | 1 | 0.0 0.0–0.0 | 0.0 0.0–1.0 | -2.33 | 0.0152 |
|         | Gold  |    | 0.0 0.0–0.0 | 0.0 0.0–1.0 | -0.87 | 0.1024 |
| EQc6.2 Controllability of systems—thermal comfort | Silver | 1 | 0.0 0.0–0.0 | 0.0 0.0–0.0 | 0.15  | 0.7725 |
|         | Gold  |    | 0.0 0.0–0.0 | 0.0 0.0–0.0 | 0.07 | 0.1816 |
| EQ7.1 Thermal comfort—design | Silver | 1 | 1.0 1.0–1.0 | 1.0 1.0–1.0 | Inf   | 0.3792 |
|         | Gold  |    | 1.0 1.0–1.0 | 1.0 1.0–1.0 | 0.06  | 0.8374 |
| EQ7.2 Thermal comfort—verification | Silver | 1 | 1.0 1.0–1.0 | 1.0 1.0–1.0 | 0.95  | 0.2285 |
|         | Gold  |    | 1.0 1.0–1.0 | 1.0 1.0–1.0 | 1.32  | 0.0221 |
| EQ8.1 Daylight and views—daylight | Silver | 2 | 0.0 0.0–1.0 | 0.0 0.0–0.0 | 0.31  | 0.0130 |
|         | Gold  |    | 0.0 0.0–1.0 | 0.0 0.0–0.0 | 0.37  | 0.0003 |
| EQ8.2 Daylight and views—views | Silver | 1 | 0.0 0.0–0.5 | 0.0 0.0–0.0 | 0.54  | 0.3582 |
|         | Gold  |    | 0.0 0.0–1.0 | 0.0 0.0–1.0 | 0.04  | 0.9033 |
| LEED-CIv4 |       |    |                                |        |    |
| EQc1 Enhanced indoor air quality strategies | Silver | 2 | 1.0 1.0–2.0 | 1.0 1.0–2.0 | -0.12 | 0.4899 |
|         | Gold  |    | 2.0 1.0–2.0 | 1.5 1.0–2.0 | 0.24  | 0.0485 |
| EQc2 Low-emitting materials | Silver | 3 | 0.0 0.0–2.0 | 1.0 1.0–3.0 | -0.32 | 0.0608 |
|         | Gold  |    | 1.0 0.0–2.0 | 1.0 0.0–3.0 | -0.10 | 0.4281 |
| EQc3 Construction indoor air quality management plan | Silver | 1 | 1.0 1.0–1.0 | 1.0 1.0–1.0 | NaN   | 0.5000 |
|         | Gold  |    | 1.0 1.0–1.0 | 1.0 1.0–1.0 | 1.21  | 0.2332 |
| EQc4 Indoor air quality assessment | Silver | 2 | 1.0 0.0–1.0 | 0.0 0.0–1.0 | 0.36  | 0.0164 |
|         | Gold  |    | 1.0 1.0–2.0 | 0.0 0.0–2.0 | 0.14  | 0.3253 |
| EQc5 Thermal comfort | Silver | 1 | 0.0 0.0–0.5 | 0.0 0.0–0.0 | 1.01  | 0.1561 |
|         | Gold  |    | 0.0 0.0–1.0 | 0.0 0.0–0.0 | 0.86  | 0.0388 |
| EQc6 Interior lighting | Silver | 2 | 0.0 0.0–1.0 | 1.0 0.0–1.0 | -0.20 | 0.2404 |
|         | Gold  |    | 1.0 0.0–1.0 | 1.0 0.0–1.0 | 0.07  | 0.5776 |
| EQc7 Daylight | Silver | 3 | 0.0 0.0–0.0 | 0.0 0.0–0.0 | 0.12  | 0.3099 |
|         | Gold  |    | 0.0 0.0–2.0 | 0.0 0.0–0.0 | 0.24  | 0.0218 |
| EQc8 Quality views | Silver | 1 | 1.0 0.0–1.0 | 0.0 0.0–1.0 | 0.86  | 0.1812 |
|         | Gold  |    | 1.0 0.0–1.0 | 1.0 0.0–1.0 | -0.12 | 0.7304 |
| EQc9 Acoustic performance | Silver | 2 | 0.0 0.0–0.0 | 0.0 0.0–0.0 | -0.05 | 0.9666 |
|         | Gold  |    | 0.0 0.0–0.0 | 0.0 0.0–0.0 | -0.06 | 0.4664 |

Notes: The P-values were evaluated according to the following three-valued logic: Bold font—seems to be positive, ordinal font size—seems to be negative, and italic font—judgment is suspended.

1. To estimate the effect size and statistical difference between China and the US, the LEED-CIv3 EQ credits were treated using the Log Odds Ratio and Fisher's exact test 2 × 2 tables with a two-tailed mid-P-value, respectively.
Buildings Except Low-Rise Residential Buildings), which was also used for the evaluation of EA points.

Concerning the LEED-CIv4 MR credits, MRc3, MRc4, and MRc5, which require the use of products/materials with life cycle assessment (LCA) declarations, were the first credits to be introduced in LEEDv4. These were noticed early and performed better in the US than in China (Table 6). This means that introducing these LCA-based credits has had a positive influence on the implementation of MR credits in the US. In addition, interesting results were revealed for the “MRc6, construction and demolition waste management” credit, where China performed better than the US (Table 6), despite the lower standard of construction waste minimization laws/regulations in China compared to the US, as discussed by Chi et al. (2020).

After analyzing the EQ credits, it was found that the main difference between LEED-CIv3 and LEED-CIv4 for the EQ credits was that 16 credits in LEED-CIv3 were converted into eight credits in LEED-CIv4, as shown in Table 7. For example, five separate credits of low-emitting materials of LEED-CIv3—“EQc4.1, adhesives and sealants,” “EQc4.2, paints and coatings,” “EQc4.3, flooring systems,” “EQc4.4, composite wood and agrifiber products,” and “EQc4.5, systems furniture and seating” (each of these credits has one awarding point)—are grouped into one category in the LEED-CIv4 system, the “EQc2, low-emitting materials” credit, with three awarding points. Thus, in contrast to the SS/LT, EA, and MR categories, in which an increasing tendency in the number of differently performing credits when certification was switched from version 3 to 4 was observed, in the EQ category, this tendency was found to be reversed. For the LEED-CIv3 Silver and Gold projects, 12 of the total 16 credits performed differently in China and the US. However, for the LEED-CIv4 Silver and Gold EQ credits, only three of the eight credits performed differently in these countries. We speculate that having a large number of separately presented credits can allow a much better adaptation of the EQ credits to country-specific environmental concerns.

5. Results and recommendations

This study has analyzed the difference between China-LEED-CI and US-LEED-CI projects for v3 and v4 at the level of Silver and Gold certificates. For LEED-CIv3, China was found to have better results than the US in the WE Silver and Gold categories with a mediate effect size (δ = 0.33 and μ = 0.34, respectively) and, for LEED-CIv4, China was found to have better results than the US in the WE Silver and Gold categories with a large effect size (δ = 0.60 and μ = 0.79, respectively). In contrast, the US was found to have better results than China in the EA Silver category with a small effect size (δ = 0.26) and in the EA Gold category with a large effect size (δ = 0.58), and, for LEED-CIv4, the US was found to have better results than China in the EA Silver and Gold categories with a large effect size (δ = 0.53 at both levels of certification). Consequently, the difference between China and the United States was recorded in two LEED-CI categories, the WE and EA categories, for the LEED-CIv3 Gold and Silver systems. This difference increased for LEED-CIv4 Gold and Silver projects. For LEED-CIv4, in addition to the existing differences in the WE and EA categories between China and the US, the LT and MR categories were identified. In LEED-CIv4, China was found to have better results than the US in the LT Silver and Gold categories with a large effect size (δ = 0.76 and μ = 0.54, respectively), whereas the US was found to have better results than China in the MR Silver and Gold categories with a large effect size (δ = 0.55 and μ = 0.48, respectively).

Therefore, a comparison between the LEED-CI v3 and v4 Silver and Gold projects showed that the differences between China and the US increased from two categories, i.e., WE and EA, in version 3 to four categories in version 4, i.e., WE, EA, LT, and MR. Thus, according to the results revealed in this study, it may be suggested the current standard, LEED-CIv4, gives more possibilities compared to the previous standard, LEED-CIv3, for emphasizing country-specific environmental priorities in China and the US.

Declarations

Author contribution statement

Svetlana Pushkar: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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