THE LEED-COMMERCIAL INTERIORS (V4) PROJECTS IN CALIFORNIA

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ABSTRACT

This study analyzed the Leadership in Energy and Environmental Design for Commercial Interior Certified, Silver, and Gold projects version 4.0 (LEED-CIv4) in California for the period 2015−2020. Nonparametric tests were used to assess category and credit achievement, i.e., the difference between possible and achieved points and the correlation between associated credits. The results show that most of the credits in the location and transportation category and the indoor environmental quality categories had a high level of achievement, a few credits in the energy and atmosphere and materials and resources categories had a high level of achievement, and all of the credits in the water efficiency category had a low level of achievement. Some associated credits, such as surrounding density and quality transit, had a high level of achievement and a positive correlation, whereas other associated credits, such as life-cycle impact reduction and environmental product declarations, had a low level of achievement and a positive correlation. If LEED-CIv4 credits meet the requirements of the California Green Building Standards Code 2016 (CGBSC 2016), then these credits typically have a medium/high level of achievement. If LEED-CIv4 credits exceed the requirements of CGBSC 2016, then these credits have a low level of achievement. Therefore, to improve the next version of LEED-CI, it is necessary to improve the local green codes.

KEYWORDS

LEED-CIv4; credit/category achievement; California building codes

INTRODUCTION

Currently, green building certification is being used to move toward a sustainable building sector. Due to inherent differences in cultural patterns and resource sources, each country has developed its own green certification system. In this respect, we can mention the following well-known and mature rating systems: the Green Star (Australia); the BRE Environmental Assessment Method (BREEAM) (the United Kingdom); the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) (Japan); and Leadership in Energy and Environmental Design (LEED) (the United States). LEED-certified projects, however, are the most extensively analyzed by researchers both in the United States and worldwide (Suzer 2015; Ma and Cheng 2016; Wu et al. 2017; Pushkar and Verbitsky 2018a).

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LEED-related empirical studies provide LEED experts with important feedback from LEED practitioners. LEED experts are responsible for further improving this system from one version to the next. Buildings can be certified under a relevant LEED system; examples are LEED-NC for new construction, LEED-EB for existing buildings, LEED-C&S for core and shell development, LEED-ND for neighborhood development, and LEED-CI for commercial interiors. According to the literature, the LEED-NC-certified projects carried out in the United States are the most analyzed (Wu et al. 2016; Wu et al. 2017; Pushkar and Verbitsky 2018a; Pushkar and Verbitsky 2019a), and the following well-grounded conclusions were drawn about this system: high achievement for the sustainable sites (SS) and innovation in design (IN) categories, medium achievement for the water efficiency (WE) and indoor environmental quality (EQ) categories, and low achievement for the energy and atmosphere (EA) and materials and resources (MR) categories.

However, these LEED-NC achievements may be irrelevant to other LEED systems. In particular, these LEED-NC achievements seem to be inappropriate for LEED-CI projects. This is because the NC system relates to building interior and exterior designs, whereas the LEED-CI system relates mostly to building interior designs (Pushkar and Verbitsky 2019b). For example, the SS category has less weight in LEED-CIv3 (21 points) than in LEED-NCv3 (26 points), while the EA category has more weight in LEED-CIv3 (37 points) than in LEED-NCv3 (35 points) (LEED-CIv3 2009; LEED-NCv3 2009).

Several researchers have performed LEED-CI-related empirical studies. Fuerst (2009) studied the LEED-CIv2 projects together with LEED-NC, LEED-EB, and LEED-C&S projects and concluded that these projects had a low level of achievement that rose just above the lower boundary of each certification level (Certified, 21–26 points; Silver, 27–31 points; Gold, 32–41 points; and Platinum, 42–57 points). However, the author did not present a separate conclusion about LEED-CIv2-certified projects.

Moreover, LEED-CIv2 included 7 points in the SS category, 2 points in the WE category, 12 points in the EA category, 14 points in the MR category, 17 points in the EQ category, and 5 points in the IN category (LEED-CIv2 2004). The third version of LEED-CI was reorganized and devoted 21, 11, 37, 14, 17, and 6 points to the SS, WE, EA, MR, EQ, and IN categories, respectively (LEED-CIv3 2009). In addition, a new regional priority (RP) category with four points was introduced in this version. RP points are awarded as a "bonus" when regional priority issues are addressed well under the SS, WE, EA, MR, or EQ categories. The total number of LEED-CIv3 points is 110; to achieve the Certified, Silver, Gold, and Platinum levels, 40–49, 50–59, 60–79, and 80−100 points, respectively, need to be obtained (LEED-CIv3 2009). The projects carried out in the United States and certified under LEED-CIv3 were studied by Pushkar and Verbitsky (2019b), who reported that the SS, WE, and ID categories had a high level of achievement, the EA and EQ categories had a medium level of achievement, and the MR category had a low level of achievement.

However, LEED-CIv4, which is the current LEED-CI system, was released in 2014 with the following modifications: the SS category was replaced with a location and transportation (LT) category; five separate credits (lighting power, lighting control, heating, ventilating, and air conditioning (HVAC) in the equipment and appliances (EA) category were combined into a single optimize energy performance credit, and four MR credits were introduced to impose life-cycle assessment (LCA) requirements (LEED-CIv4 2014). Therefore, the LEED-CIv3 project achievements should be verified using LEED-CIv4 project achievements.

The present study focused on LEED-CIv4 projects certified in California in the United

States. California was selected as a case study due to its strong preference for sustainable policies. In terms of operational energy issues, which are related to the optimize energy performance credit (in the EA category) of the LEED-CI system, California constantly adopts a stricter version of ASHRAE 90.1 (the Energy Standard for Buildings Except Low-Rise Residential Buildings). In 2015, California adopted ASHRAE 90.1-2010; in 2016, California adopted ASHRAE 90.1-2013; and in 2017, California adopted ASHRAE 90.1-2016 (ASHRAE 90.1). Californian municipalities require all large municipal building projects to be LEED-certified. For example, in San Francisco, municipal public buildings with a gross square footage greater than 10,000 need to be constructed in accordance with the LEED Gold certification (city and county of San Francisco, Green Building Code 2017). Californian cities redevelop their downtown areas by applying form-based codes (FBCs), which are strongly related to the smart location and linkage and neighborhood pattern and design categories of LEED-ND (Garde 2018). As a result of this implementation of LEED, California now has the highest number of LEED-certified buildings (Simcoe and Toffel 2014; Shin et al. 2017).

The aim of this study was to determine the trends in LEED-CIv4-certified projects in California for the period 2015−2020 through evaluating: (i) category achievement; (ii) credit achievement; and (iii) correlations between associated credits. We selected the period 2015–2020 because a suitable sample size of observational data was available for this period. We also identified high-achieving categories/credits and low-achieving categories/credits.

It should be noted that, as we only analyzed projects that were certified in California, our findings are not generalizable. Pushkar and Verbitsky (2018a) recently analyzed LEED-NCv3-certified projects in California, Florida, Illinois, Massachusetts, Virginia, Washington, New York, Ohio, Texas, and Georgia in the United States. The authors showed that, in the EA Gold category, California has significantly higher rates than the other nine states. Therefore, each state should first be considered separately, since each state has its own green building strategy (Pushkar 2018).

This study also offers a methodology that future studies may use. Adopting a separate evaluation of different areas with different economic, social, and technological contexts may help to accumulate data on LEED-specific strategies in these areas. In turn, such data may help LEED developers to build a flexible weighting system for the adaptation of LEED points to other countries according to their environmental needs.

METHODS

Data Collection

In this study, we analyzed Certified, Silver, and Gold LEED-CI projects in California. Seventeen (17) Certified, 27 Silver, 20 Gold, and 2 Platinum projects that were certified during the period March 2015 to May 2020 were discovered in the United States Green Building Council (USGBC) project directory (USGBC). We excluded the Platinum projects from the statistical analysis. Pushkar and Verbitsky (2019b) recently analyzed the 2009 LEED-CI projects in California and showed that the sample size (n) in both groups (n_1 and n_2), $n_1 = n_2 = 20$, was statistically significantly different (a low *p*-value) when the effect size was medium or higher.

Table 1 presents the distribution of the analyzed projects in Californian cites. The scorecards of all of the projects, which contain their achieved points in the IP, LT, WE, EA, MR, EQ, IN, and RP categories, were downloaded from the USGBC directory. The data were collated in an Excel database.

TABLE 1. Distribution of LEED-CIv4 Certified, Silver, and Gold projects in California, United States in the period 2015–2020.

Certification	City (Number of Projects)
Certified	Alameda (1), Irvine (1), Los Angeles (1), Oakland (1), Sacramento (2), San Diego (3), San Francisco (2), San Jose (1), San Mateo (2), South San Francisco (1), Tustin (1), West Hills (1)
Silver	Grove (1), Livermore (1), Los Angeles (3), Oakland (1), Pacoima (1), Rancho Cordova (1), Sacramento (4), San Diego (1), San Francisco (7), San Jose (1), San Mateo (1), South San Francisco (2), Sunnyvale (1), West Sacramento (2)
Gold	Fremont (1), Los Angeles (3), Menlo Park (2), Mountain View (1), Sacramento (1), San Diego (1), San Francisco (7), Santa Monica (1), South San Francisco (1), Sunnyvale (2)

Statistical analysis

For the descriptive statistics, we used the median and the 25th–75th centiles instead of the mean ± standard deviation because LEED data are associated with an ordinal scale. For the inferential statistics, we used the exact Wilcoxon–Mann–Whitney (WMW) nonparametric test and Cliff's δ effect size nonparametric test instead of the parametric *t*-test and Cohen's d effect size or another parametric effect size test, respectively, because the assumption of normality for LEED data was not met. We applied the exact instead of the asymptotic approximation WMW test because one of the two groups contained the same values (a "somewhat unusual dataset") (Bergmann et al. 2000). It should be noted that the WMW procedure tests for equality of group mean-ranks, not of group medians (Bergmann et al. 2000), and Cliff's δ effect size determines the magnitude of the difference of two distributions (Cliff 1993). In the present study, we used Cliff's $1 - |\delta|$ to evaluate the effect size of the achieved points. According to Romano et al. (2006), the effect size is considered to be (i) negligible if $|\delta| < 0.147$; (ii) small if $0.147 \le |\delta| < 0.33$; (iii) medium if $0.33 \le |\delta| < 0.474$; and (iv) large if $|\delta| \ge 0.474$.

If the LEED data had binary ("0" or "1") variables, then we used Fisher's exact 2 × 2 test with a two-tailed Lancaster's mid-*p*-value (Lancaster 1961; Routledge 1992) instead of the exact WMW test. The natural logarithm of the odds ratio can be used instead of Cliff's δ for binary variables. In the context of the current study, the natural logarithm of the odds ratio cannot be used as an indicator of the magnitude of the effect, since one of the proportions in the fourfold table is zero. However, using the Fleiss procedure (Fleiss 1981 cited by Haddock et al. 1998), namely adding 0.5 to each observed frequency, may not work because the values in the other cells of the fourfold table are zero (Haddock et al. 1998, p. 343). We also used the nonparametric Spearman rank order correlation test instead of the parametric ordinary least squares method because the Gauss–Markov assumptions were not met. Recently, Pushkar and Verbitsky (2018b) used a Spearman correlation test to evaluate the relationship between building and service layers in both LEED-NCv3 and LEED-EBv3 projects.

In the present study, the WMW two-tailed test or Fisher's exact 2 × 2 test with a two-tailed Lancaster's mid-*p*-value was used to estimate the statistical difference between possible and achieved points in a category and credit for each certification level of LEED-CIv4 projects.

The Spearman correlation test evaluates the correlation coefficient (*r*) and two-tailed *p*-value: the strength of the relationship and statistical difference, respectively, between two correlated credits.

The *p*-values were evaluated according to three logical statements: "it seems to be positive"; "it seems to be negative"; and "judgment is suspended" (Hurlbert and Lombardi, 2009).

In order to evaluate the difference between possible and achieved points, "it seems to be positive" indicates that there seems to be a difference between possible and achieved points while "it seems to be negative" indicates that there does not seem to be a difference between possible and achieved points. The "judgment is suspended" statement indicates that the judgment relating to a difference between possible and achieved points is suspended.

In order to evaluate the correlation between two associated credits, "it seems to be positive" indicates that there seems to be a correlation between the achieved points of two associated credits, "it seems to be negative" indicates that there does not seem to be a correlation between the achieved points of two associated credits, and "judgment is suspended" indicates that the judgment relating to the correlation between the achieved points of two associated credits is suspended.

RESULTS AND DISCUSSION

LEED-CIv4 categories

In the IP category, the Gold projects showed a high level of achievement, whereas the Certified and Silver projects demonstrated a low level of achievement (Table 2). The IP category includes only one credit that requires a preliminary analysis of the relationships between energy-related and water-related systems. It can be supposed that the preliminary analysis was more effective for Gold projects, which focused on emphasizing the EA category (a median of 24.0 points from 38 possible points, Table 2). In the IN category, the Silver and Gold projects had a high and medium level of achievement, respectively. RP allows for the award of up to four possible bonus points by achieving regional-issue-related credits in the LT, WE, EA, MR, and EQ categories. These regional issues were emphasized only in the Gold projects (a medium level of achievement).

The WE category of LEED-CIv4 also includes only one credit, namely indoor water use reduction (with 12 possible points). This credit had a similarly low level of achievement at each of the three certification levels, as potable water use was decreased by approximately 35% (6 achieved points, Table 2) from the calculated baseline in the indoor water use reduction prerequisite, whereas a 50% reduction in potable water use is required to receive all of the 12 possible points. This achievement in the WE category of the LEED-CIv4 by Silver and Gold projects (a median of 6.0 points from 12 possible points, Table 2) was comparable to that in the WE category of the LEED-CIv3 by Silver and Gold projects (a median of 8.0 points from 11 possible points) in California, as presented earlier by Pushkar and Verbitsky (2019b). It should be noted that California is located in a high water stress area (https://www.globalchange.gov/browse/multimedia/water-stress-us). Thus, California has attempted to save potable water by requiring Title 24, Section 4.3 (Water efficiency and conservation) of California's Code of Regulations to apply under California's Green Building Standards Code 2016 (CGBSC, 2016). In this respect, the LEED-CIv4 WE category prerequisite (decreasing potable water use by 20% from the calculated baseline) is equivalent to the CGBSC 2016 water reduction requirement (Greer et al. 2019). As was noted above, a reduction in potable water use of approximately

35% from the calculated baseline was preferred in the LEED-CIv4 projects irrespective of their certification level. Thus, in the WE category, design teams performed slightly better than is required by California's local building code (CGBSC, 2016).

The achievement level in the LT, EA, MR, and EQ categories of the LEED-CIv4 projects was low at each of the three certification levels (Table 2). Moreover, the achievement level in the EA category of the LEED-CIv4 projects remained unchanged (a median of 17.0 and 24.0 points from 38 possible points, Table 2) from that in the EA category of LEED-CIv3 projects (a median of 16.5 and 23.0 points from 37 possible points (Pushkar and Verbitsky, 2019b)) for Silver and Gold, respectively. The achievement level in the MR category of the LEED-CIv4 projects was somewhat higher (a median of 5.0 and 6.0 points from 13 possible points, Table 2) than that in the MR category of LEED-CIv3 projects (a median of 4.5 and 5.5 points from 14 possible points (Pushkar and Verbitsky, 2019b)) for Silver and Gold, respectively. The achievement level

TABLE 2. Credit points achieved in the LEED-CIv4 categories by projects certified in California, USA during the period 2015–2020. The data are expressed as the median and the 25th–75th centiles and Cliff's 1 – |δ| effect size of the achieved points. The *p*-values in all comparisons were $p \leq 0.0002$ and are not shown in Table 2.

Category	Possible points	Achieved points		
		Certified	Silver	Gold
Integrative Process	2	0.0 0.0–2.0	0.0 0.0–1.8	2.0 0.5–2.0
		0.29	*0.26*	**0.55**
Location and Transportation	18	8.0 3.0–15.0	8.0 3.0–15.0	16.5 15.0–18.0
		0.00	0.00	*0.15*
Water Efficiency	12	6.0 4.0–6.5	6.0 4.5–8.0	6.0 5.0–8.0
		0.12	0.11	0.05
Energy and Atmosphere	38	13.0 10.0–14.0	17.0 12.0–25.5	24.0 15.5–27.0
		0.00	0.00	0.00
Materials and Resources	13	3.0 1.8–5.3	5.0 4.0–7.0	6.0 4.5–6.0
		0.00	0.00	0.00
Indoor Environmental Quality	17	4.0 3.8–5.0	5.0 4.3–6.0	7.0 5.5–8.5
		0.00	0.00	0.00
Innovation	6	4.0 2.0–4.3	5.0 5.0–6.0	5.0 4.5–6.0
		0.12	**0.48**	***0.40***
Regional Priority	4	1.0 1.0–2.3	3.0 2.0–3.0	3.0 3.0–4.0
		0.06	0.07	***0.45***

The δ 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.

in the EQ category of the LEED-CIv4 projects was somewhat lower (a median of 5.0 and 7.0 points from 17 possible points, Table 2) than that in the EQ category of LEED-CIv3 projects (a median of 7.0 and 9.0 points from 17 possible points (Pushkar and Verbitsky, 2019b)) for Silver and Gold, respectively.

To determine whether the credits in the LT, EA, MR, and EQ categories were achieved successfully or unsuccessfully, further detailed analyses of these categories, covering both credit achievement and correlations, were performed. The results are presented in Tables 3–10.

TABLE 3. Credit points achieved in the location and transportation (LT) category of LEED-CIv4 by projects certified in California, USA during the period 2015–2020. The data are expressed as the median and the 25th–75th centiles and Cliff's $1 - |\delta|$ effect size of the achieved points. The *p*-values in all comparisons were $p \leq 0.0012$ and are not shown in Table 3.

Credit	Possible points	Achieved points		
		Certified	Silver	Gold
Surrounding density and diverse uses (LTc2)	8	5.0 2.0–8.0	5.0 2.0–8.0	8.0 5.0–8.0
		0.47	***0.44***	**0.55**
Access to quality transit (LTc3)	7	3.0 0.0–7.0	3.0 0.0–7.0	7.0 3.8–7.0
		0.41	***0.33***	**0.55**
Bicycle facilities (LTc4)[1]	1	0.0 0.0–0.0	0.0 0.0–0.0	0.0 0.0–0.8
		0.24	*0.26*	***0.40***
Reduced parking footprint (LTc5)	2	0.0 0.0–0.0	0.0 0.0–0.0	2.0 0.0–2.0
		0.12	*0.15*	***0.45***

The δ effect size is considered to be (i) negligible if $|\delta| < 0.147$; (ii) *small* if $0.147 \leq |\delta| < 0.33$; (iii) ***medium*** if $0.33 \leq |\delta| < 0.474$; and (iv) **large** if $|\delta| \geq 0.474$.

[1]To estimate the statistical difference between possible and achieved points, the LEED-CIv4 LTc4 credit data were tested using Fisher's exact test with 2 × 2 tables and a two-tailed mid-*p*-value.

Data on LEED for neighborhood development location (LTc1) are not presented because none of the analyzed projects achieved this credit.

TABLE 4. The correlation between associated credits in the location and transportation category of LEED-CIv4 for each certification level. The table shows the correlation coefficient (*r*) and *p*-value between correlated credits.

Associated credits	Certified		Silver		Gold	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value
LTc2 and LTc3	0.88	**0.00001**	0.77	**0.00001**	0.86	**0.00001**

Bold = there seems to be a correlation between the achieved points of two associated credits; ordinal = there does not seem to be a correlation between the achieved points of two associated credits; italic = judgment is suspended regarding the correlation between the achieved points of two associated credits.

Location and Transportation

The surrounding density and diverse uses of (LTc2) and access to (LTc3) quality transit are location-related credits. Certified and Silver projects demonstrated a medium level of achievement in these credits, and Gold projects demonstrated a high level of achievement in these credits (Table 3). These credits depend on the walking distance between a project and general public services, such as supermarkets, banks, education facilities, and restaurants (LTc2), as well as public transportation services, such as bus stops, rail stations, and ferry terminals (LTc3). A high/medium level of achievement in LTc2 and LTc3 is to be expected in California because close proximity between general public and transportation services and the housing sector is also encouraged by other sustainable policies, such as form-based codes (FBCs). It should be noted that FBCs are aimed at downtown redevelopment (Garde, 2018) and, therefore, compliance with them can be accomplished through LEED-CI certification. Moreover, these general public and transportation services are simultaneously available in a city's infrastructure. Therefore, in the Certified, Silver, and Gold projects, a high degree of correlation was found between the LTc2 achieved points and the LTc3 achieved points (Table 4).

In the bicycle facilities (LTc4) and reduced parking footprint (LTc5) credits, the analysis revealed that Certified and Silver projects had a low level of achievement and Gold projects had a medium level of achievement (Table 3). LTc4 and LTc5 are transport-related credits that require a transition in the public transportation system from private car ownership to the use of bikes and carpooling. LTc4 requires the installation of project-related bicycle storage and showers with clothes-changing facilities for a building's occupants and visitors, and LTc5 requires the project to give priority to carpool parking. This transition in the transportation system involves the use of supplemental transportation infrastructure, such as separate routes for cycling (which may be unavailable in the project's neighborhood), and a decrease in the number of private parking spaces (which may be unpopular with future residents). LTc4 and LTc5 are separate and disconnected credits. Therefore, in this case, a correlation analysis was not necessary.

It should be noted that California's Code of Regulations (Title 24, Section 5.106.4 Bicycle parking (CGBSC, 2016)) also requires that a project "… provide secure bicycle parking for 5 percent of the tenant vehicular parking spaces being added, with a minimum of one bicycle parking facility" (CGBSC, 2016). However, CGBSC 2016 does not prescribe any requirements for showers with clothes-changing facilities. This may be viewed as an obstacle to a high level of performance in the LTc4 credit. However, with regard to low-emission, fuel-efficient, and carpool/vanpool vehicles, California's Code of Regulations (Title 24, Section 5.106.5.2 Designated Parking for Clean Air Vehicles (CGBSC, 2016)) imposes more strict requirements (8% of the total number of parking spaces must be for clean air vehicles) than LTc5, which requires that 5% of the total number of parking spaces be for clean air vehicles.

Energy and Atmosphere

The LEED-CIv4 projects certified in California showed a low level of achievement at each of the three certification levels in the enhanced commissioning (EAc1) and advanced energy metering (EAc2) credits (Table 5). These credits require tenant-level commissioned surveys of mechanical, electrical, domestic hot water, and renewable energy systems (EAc1) and the installation of advanced energy system metering systems (EAc2). EAc1 and EAc2 are separate and disconnected credits, so we did not need to perform a correlation analysis.

Renewable energy production (EAc3) and green power and carbon offsets (EAc5) are green-energy-related credits. EAc3 aims to reduce the environmental damage caused by

TABLE 5. Credit points achieved in the energy and atmosphere (EA) category of LEED-CIv4 by projects certified in California, USA during the period 2015–2020. The data are expressed as the median and the 25th–75th centiles and Cliff's $1 - |\delta|$ effect size of the achieved points. The *p*-values in all comparisons were $p \leq 0.0083$ and are not shown in Table 5.

		Achieved points		
Credit	Possible points	Certified	Silver	Gold
Enhanced commissioning (EAc1)	5	4.0 4.0–4.0	4.0 4.0–4.0	4.0 4.0–4.8
		0.12	*0.26*	*0.25*
Advanced energy metering (EAc2)	2	0.0 0.0–1.0	0.0 0.0–1.0	1.0 0.0–1.8
		0.12	0.04	*0.25*
Renewable energy production (EAc3)	3	0.0 0.0–0.0	0.0 0.0–0.0	0.0 0.0–1.5
		0.00	0.11	0.10
Enhanced refrigerant management (EAc4)[1]	1	0.0 0.0–0.0	0.0 0.0–1.0	0.0 0.0–0.0
		0.24	***0.33***	*0.25*
Green power and carbon offsets (EAc5)	2	0.0 0.0–2.0	2.0 0.0–2.0	2.0 1.3–2.0
		0.29	**0.48**	**0.65**
Optimized energy performance (EAac6)	25	8.0 7.0–8.0	11.0 7.0–18.0	16.0 11.0–18.8
		0.00	0.07	0.05

The δ effect size is considered to be (i) negligible if $|\delta| < 0.147$; (ii) *small* if $0.147 \leq |\delta| < 0.33$; (iii) ***medium*** if $0.33 \leq |\delta| < 0.474$; and (iv) **large** if $|\delta| \geq 0.474$.
[1]To estimate the statistical difference between possible and achieved points, the LEED-CIv4 Eac4 credit data were tested using Fisher's exact test with 2 × 2 tables and a two-tailed mid-*p*-value.

fossil-fuel-based energy by requiring the direct installation of renewable energy systems or the purchase of renewable power from other sources. EAc5 relates to entering into a contract for qualified resources of green power, carbon offsets, or renewable energy certificates. However, we found that the analyzed projects achieved these credits differently: EAc3 had a low level of achievement in Certified, Silver, and Gold projects, while EAc5 had a low level of achievement in Certified projects and a high level of achievement in Silver and Gold projects (Table 5). This occurred despite a correlation being revealed between the achievement of these credits at the Silver and Gold certification levels, which indicated a connection between the credits (Table 6).

Enhanced refrigerant management (EAc4) and optimized energy performance (EAc6) are operational energy-related credits. EAc4 prohibits refrigerants in order to decrease environmental impacts, including global warming potential (GWP) and ozone depletion potential. EAc6 requires thermally efficient building envelopes to be insulated and a decrease in the operational energy and, thereby, GWP of energy-efficient HVAC systems, interior lighting power and controls, and equipment and appliances. Despite the importance of the energy-saving issues expressed in these credits, these requirements still found less recognition because both credits

TABLE 6. Correlation between associated credits in the energy and atmosphere category of LEED-CIv4 at each level of certification. The table shows the correlation coefficient (*r*) and *p*-value between correlated credits.

Associated credits	Achieved points					
	Certified		Silver		Gold	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value
Eac3 and Eac5	0.61	**0.0087**	0.55	**0.0030**	0.46	**0.0399**
Eac4 and Eac6	0.65	**0.0045**	0.49	**0.0102**	0.30	0.2059

Bold = there seems to be a correlation between the achieved points of two associated credits; ordinal = there does not seem to be a correlation between the achieved points of two associated credits; italic = judgment is suspended regarding the correlation between achieved points of two associated credits.

had a low level of achievement at each of the three certification levels (the only exception being a medium level of achievement by Silver projects in EAc4) (Table 5). These mostly low levels of achievement showed that there was a correlation between EAc4 and EAc6 in Certified and Silver projects (Table 6). The low level of achievement in the optimized energy performance (EAc6) credit by LEED-CIv4 projects certified in California was somewhat surprising because the strictest version of ASHRAE 90.1-2016 (ASHRAE 90.1) was adopted in this State in 2017. However, according to an earlier analysis of LEED-NCv3 projects certified in California, a strategy that emphasizes energy-saving is a responsible strategy for moving projects from Silver to Gold (Pushkar and Verbitsky 2018a). It seems that the same trend was revealed in the LEED-CIv4 Silver and Gold projects (a median of 16.0 achieved points in Gold versus a median of 11.0 achieved points in Silver, Table 5).

Materials and Resources

After analyzing the LEED-CIv4 projects carried out in California, the Certified, Silver, and Gold projects were found to have a high level of achievement in the long-term commitment (MRc1) credit (Table 7). This credit requires tenants to commit to staying in the same building for at least 10 years, thereby decreasing the amount of environmental damage from the production and transport of materials during tenant relocation. MRc1 is a separate credit not connected with any other credit; so, in this case, a correlation analysis was not performed.

The newly introduced credits in LEED-CIv4 are interiors life-cycle impact reduction (MRc2), building product disclosure and optimization (BPD and O)—environmental product declarations (MRc3), BPD and O—sourcing of raw materials (MRc4), and BPD and O—material ingredients (MRc5), which are life-cycle-related credits. The MRc2 credit requires interior reuse, furniture reuse, and/or a flexible interior design during the building's life cycle, while the MRc3−MRc5 credits require the use of products and materials with a life-cycle assessment declaration. All of these credits had a low level of achievement in the Certified, Silver, and Gold projects (Table 7) carried out in California, and most were found to be correlated with each other (Table 8). Such correlated low levels of achievement in the life-cycle-related credits may be explained by an unwillingness to increase a project's cost due to the necessity of developing

TABLE 7. Credit points achieved in the materials and resources (MR) category of LEED-CIv4 by projects certified in California, USA during the period 2015–2020. The data are expressed as the median and the 25th–75th centiles and Cliff's 1 – |δ| effect size of the achieved points. The *p*-values in all comparisons were $p \le .0471$ and are not shown in Table 7.

Credit	Possible points	Achieved points		
		Certified	Silver	Gold
Long-term commitment (MRc1)[1]	1	1.0 0.0–1.0	1.0 0.0–1.0	1.0 0.3–1.0
		0.71	**0.63**	**0.70**
Interiors life-cycle impact reduction (MRc2)	4	0.0 0.0–1.0	0.5 0.0–1.0	1.0 0.3–1.0
		0.06	0.00	0.00
BPD and O—environmental product declarations (MRc3)	2	0.0 0.0–1.0	1.0 0.0–1.0	1.0 0.0–1.0
		0.00	0.00	0.05
BPD and O—sourcing of raw materials (MRc4)	2	0.0 0.0–1.0	1.0 0.0–1.0	1.0 0.0–1.0
		0.00	0.04	0.05
BPD and O—material ingredients (MRc5)	2	0.0 0.0–0.7	1.0 0.0–1.0	1.0 0.3–1.0
		0.06	0.19	0.00
Construction and demolition waste management (MRc6)	2	1.0 0.3–2.0	1.5 1.0–2.0	2.0 2.0–2.0
		0.47	**0.52**	**0.75**

The δ 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.

[1]To estimate the statistical difference between possible and achieved points, the LEED-CIv4 MRc1 credit data were tested using Fisher's exact test with 2 × 2 tables and a two-tailed mid-*p*-value.

TABLE 8. Correlation between associated credits in the materials and resources category of LEED-CIv4 at each certification level. The table shows the correlation coefficient (*r*) and *p*-value between correlated credits.

Associated credits	Certified		Silver		Gold	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value
MRc2 and MRc3	0.67	**0.0031**	0.50	**0.0073**	0.25	0.2796
MRc2 and MRc4	0.46	***0.0607***	0.28	0.1592	0.51	**0.0221**
MRc2 and MRc5	0.78	**0.0002**	0.33	0.0895	0.48	**0.0323**
MRc3 and MRc4	0.49	**0.0461**	0.59	**0.0011**	0.55	**0.0121**
MRc3 and MRc5	0.78	**0.0003**	0.82	**0.00001**	0.86	**0.00001**

Bold = there seems to be correlation between the achieved points of two associated credits; ordinal = there does not seem to be a correlation between the achieved points of two associated credits; italic = judgment is suspended regarding the correlation between the achieved points of two associated credits.

more complicated and flexible interior designs and involving LCA-related consultants, software tools, and datasets.

The construction and demolition waste management credit (MRc6) requires that up to 75% of nonhazardous construction and demolition materials be recovered, reused, and recycled. In California, there was a medium level of achievement in Certified projects and a high level of achievement in Silver and Gold projects in this credit (Table 7). The successful achievement of this credit may be due to California's Code of Regulations, Title 24, Section 5.408.1 Construction Waste Management, which prescribes: "Recycle and/or salvage for reuse a minimum of 65 percent of the nonhazardous construction and demolition waste" (CGBSC, 2016). MRc6 is also a separate credit not connected with any other credit; so, in this case, a correlation analysis was not necessary.

Indoor Environmental Quality

Enhanced indoor air quality strategies (EQc1) is an exterior-contamination-related credit that aims to capture exterior contamination before its entry into the interior of a building by installing entryway systems and air filtration. In this credit, Certified LEED-CI projects certified in California showed a medium level of performance and Silver and Gold LEED-CI projects certified in California showed a high level of performance (Table 9). Low-emitting materials (EQc2) is an interior-contamination-related credit that requires a designer to use interior materials and products, such as paints, adhesives, sealants, composite wood, and furniture, that contain low amounts of volatile organic compounds. In this credit, Certified LEED-CI projects certified in California showed a low level of performance and Silver and Gold LEED-CI projects certified in California showed a high level of performance (Table 9). Such high levels of achievement in EQc1 and EQc2 are to be expected because of the strict exterior and interior-contamination-related requirements prescribed by California's Code of Regulations, Title 24, Section 5.504 Pollutant Control (CGBSC, 2016). EQc1 (the exterior-contamination-related credit) and EQc2 (the interior-contamination-related credit) are not connected; so, in this case, a correlation analysis was not necessary.

The construction indoor air quality management plan (EQc3) is a construction-related credit that requires, during construction and renovation, HVAC systems with a minimum efficiency reporting value of 8 to be installed. Indoor air quality assessment (EQc4) is an occupancy-related credit that requires, before or during occupancy, the flushing-out of the space with outdoor air and the installation of new filtration media. EQc3 had a high level of achievement in the Certified, Silver, and Gold LEED-CI projects certified in California, whereas EQc4 had a high level of achievement in Gold LEED-CIv4 projects and a low level of achievement in Certified and Silver LEED-CIv4 projects certified in California (Table 9). The high level of achievement in EQc3 is to be expected because of the similar requirements prescribed by California's Code of Regulations, Title 24, Section 5.504.1 Temporary ventilation, which states the following: "If the HVAC system is used during construction, use return air filters with a Minimum Efficiency Reporting Value (MERV) of 8" (CGBSC, 2016). EQc3 and EQc4 are separate credits; therefore, a correlation analysis was not performed.

Thermal comfort (EQc5) relates to the installation of control systems for the regulation of air temperature, humidity, and speed in occupied spaces. In projects certified in California during the period 2015–2020, this credit had a low level of achievement at all three certification levels of LEED-CIv4 (Table 9). EQc5 is a separate credit not connected with any other credit; so, in this case, a correlation analysis was not necessary.

TABLE 9. Credit points achieved in the indoor environmental quality (EQ) category of LEED-EBv4 by projects certified in California, USA during the period 2015–2020. The data are expressed as the median and the 25th–75th centiles and Cliff's 1 – |δ| effect size of the achieved points. The *p*-values in all comparisons were $p \leq 0.0012$, except for the EQc3 credits, and are not shown in Table 9.

Credit	Possible points	Achieved points		
		Certified	Silver	Gold
Enhanced indoor air quality strategies (EQc1)	2	1.0 0.0–2.0	1.0 0.0–2.0	2.0 1.0–2.0
		0.35	***0.41***	**0.55**
Low-emitting materials (EQc2)	3	0.0 0.0–1.0	1.0 0.0–3.0	2.0 0.0–3.0
		0.18	**0.48**	**0.50**
Construction indoor air quality management plan (EQc3)[1]	1	1.0 1.0–1.0	1.0 1.0–1.0	1.0 1.0–1.0
		1.00 (0.5000)[2]	**1.00** (0.5000)[2]	**0.95** (0.2500)[2]
Indoor air quality assessment (EQc4)	2	1.0 0.0–1.7	0.0 0.0–1.0	2.0 0.0–2.0
		0.24	0.04	**0.55**
Thermal comfort (EQc5)[1]	1	0.0 0.0–0.0	0.0 0.0–0.0	0.0 0.0–0.8
		0.00	0.11	*0.20*
Interior lighting (EQc6)	2	0.0 0.0–1.0	1.0 0.0–1.0	0.0 0.0–1.0
		0.06	0.04	0.10
Daylight (EQc7)	3	0.0 0.0–0.0	0.0 0.0–0.0	0.0 0.0–0.0
		0.00	0.00	0.00
Quality views (EQc8)[1]	1	0.0 0.0–0.7	0.0 0.0–1.0	0.0 0.0–1.0
		0.24	***0.37***	***0.45***
Acoustic performance (EQc9)	2	0.0 0.0–0.0	0.0 0.0–0.0	0.0 0.0–0.0
		0.00	0.00	0.00

The δ effect size is considered to be (i) negligible if $|\delta| < 0.147$; (ii) *small* if $0.147 \leq |\delta| < 0.33$; (iii) ***medium*** if $0.33 \leq |\delta| < 0.474$; and (iv) **large** if $|\delta| \geq 0.474$.
[1]To estimate the statistical difference between possible and achieved points, the LEED-CIv4 EQc3, EQc5, and EQc8 credit data were tested using Fisher's exact test with 2 × 2 tables and a two-tailed mid-*p*-value.
[2]The numbers in brackets represent the *p*-values.

Interior lighting (EQc6) is an artificial-lighting-related credit that requires the installation of lighting controls and/or qualitative light fixtures. Daylight (EQc7) is a daylight-related credit that requires the provision of maximum daylight and the installation of glare-control devices. EQc6 and EQc7 had a low level of achievement in the Certified, Silver, and Gold LEED-CIv4 projects certified in California (Table 9). These credits seem to be unrelated; however their low levels of achievement were found to be correlated at all three levels of certification (Table 9). Quality views (EQc8) requires the installation of window glazing for most regularly occupied spaces and, therefore, this credit is associated with window design. EQc8 showed a low level of achievement in Certified LEED-CIv4 projects and a medium level of achievement in Silver

TABLE 10. Correlation between associated credits in the indoor environmental quality category of LEED-CIv4 at each certification level. The table shows the correlation coefficient (*r*) and *p*-value between correlated credits.

Associated credits	Certified		Silver		Gold	
	r	*p*-value	*r*	*p*-value	*r*	*p*-value
EQc6 and EQc7	0.62	**0.0076**	0.60	**0.0008**	0.60	**0.0051**
EQc7 and EQc8	0.73	**0.0009**	0.67	**0.0001**	0.64	**0.0024**

Bold = there seems to be a correlation between the achieved points of two associated credits; ordinal = there does not seem to be a correlation between the achieved points of two associated credits; italic = judgment is suspended regarding the correlation between the achieved points of two associated credits.

and Gold LEED-CIv4 projects certified in California. However, EQc8 and EQc7's levels of achievement were correlated at all three levels of certification (Table 10).

Acoustic performance (EQc9) requires sounds to be isolated in order to reduce the levels of background noise from HVAC systems. This credit had a low level of performance in the Certified, Silver, and Gold LEED-CIv4 projects certified in California (Table 9). EQc9 is a separate credit not connected with any other credit; so, in this case, a correlation analysis was not necessary.

CONCLUSIONS

In this study, we analyzed building projects carried out in California, United States that received Certified, Silver, or Gold certification under LEED-CIv4 during the period 2015−2020. In general, we concluded that, in the LT and EQ categories, most of the credits had a high/medium level of achievement; in the EA and MR categories, only a few credits had a high/medium level of achievement; and in the WE category, all credits had a low level of achievement. We noticed that the credits that were achieved to a high/medium level belonged to two different groups. The first group includes credits that had a high level of achievement at the Certified, Silver, and Gold level of certification, whereas the second group includes credits whose level of achievement increased as the certification level increased from Certified to Silver and from Silver to Gold. This means that, in the future LEED versions, the credits in the second group need to be reanalyzed in order to increase their attractiveness at all certification levels. This may be done, for example, by enhancing local green codes, such as CGBSC (2016). This suggestion is based on the following tendency that was revealed in this study: those credits with requirements that are equivalent to the CGBSC 2016 requirements were mostly achieved to a high/medium level, whereas those credits whose requirements are more onerous compared with the CGBSC (2016) requirements were mostly achieved to a low level.

In addition, two particular points can be made. According to the results of the present study, the IP credit had a medium level of achievement in Gold projects only; in Certified and Silver projects, this credit had a low level of achievement. This credit requires preliminary analyses of energy-related and water-related systems. Therefore, the IP credit can be considered to be related to both water efficiency (the WE category) and optimized energy performance (the EA category), for which the level of achievement was also low in LEED-CI projects certified in California. In this respect, to increase the attractiveness of these credits, it is desirable to establish stronger connections between the IP and water efficiency credits and between the IP and optimized energy performance credits. This suggests that the IP credit is a prerequisite for these water-related and energy-related credits.

An additional source of potential for further improvement is the newly introduced life-cycle-related credits, interiors life-cycle impact reduction, BPD and O—environmental product declarations, BPD and O—sourcing of raw materials, and BPD and O—material ingredients (the MR category). These credits were also demonstrated to have a low level of achievement and were found to be correlated with each other. A low level of achievement in the MR category was confirmed in an earlier study on the projects certified under LEED-CIv3 (Pushkar and Verbitsky 2019b). However, despite the introduction of the consideration of LCA in the MR category of LEED-CIv4, the popularity of this category was found to not be significantly increased. Thus, these LCA-related credits require further attention from LEED experts.

The results of our analysis on the LEED projects certified in California during the period 2015–2020 cannot be generalized to the United States as a whole. However, the results of our study do allow us to identify the effect on a relatively small sample size. Thus, a similar methodology can be applied to the evaluation of LEED projects in other states (Pushkar and Verbitsky 2019b). In contrast, pooling the LEED projects from different states can lead to sacrificial pseudoreplication (Pushkar 2918), i.e., "artificially inflated degrees of freedom, giving the illusion of having a more powerful test than the data support" (Picquelle and Mier 2011).

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