An Investigation of the Selection of LEED Version 4 Credits for Sustainable Building Projects

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Featured Application: The results of this study are the suggestion for the project team to select the green building strategies (especially the LEED project) in the early stages of the project.

Abstract: The U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) certification program supports sustainable construction as part of the effort to address climate change and resource depletion. It is the world's most popular green building certification system, with more than 146,400 projects. Satisfying the LEED requirements brings many benefits to a project's design performance and adds community value, but it does incur additional costs and challenges. This study examined the choices made by those working on the 222 LEED New Construction version 4 (LEED-NC-V4) projects that were certified between September 2014 and March 2020 to determine how the LEED project teams selected appropriate LEED goals. The results reveal interesting insights into the way project LEED goals and the credits corresponding to the target certification level were chosen, as well as the links and trade-offs between the various credit options. Based on these findings, useful suggestions are made for ways to help LEED project teams achieve their target certification levels and encourage authorities to continue to improve their local green regulations. The analysis of actual certified projects' data makes it possible to re-evaluate the effects of newly updated requests in LEED v4 in the light of the stated goals of the USGBC.

Keywords: green building; LEED; sustainable development; efficiency building; rating tools

1. Introduction

Considerable evidence has accumulated regarding the long-term benefits of sustainable construction, especially improved energy efficiency, better financial returns, higher labor productivity, and ultimately, the reductions in global warming achieved [1,2]. The construction industry's huge economic contribution and high energy/resource consumption in economies around the world highlight its enormous potential for significantly reducing/mitigating climate change compared with other major sectors [3–5]. Dean et al. predicted that future developments in sustainable construction would reduce energy consumption by up to 50% and help limit global warming to 2 °C by 2050 [5]. Other studies have identified additional advantages of green buildings, such as reduced operating costs, adding 3–9% to the final value of the structure [6], and higher rental premiums of approximately 3–5% and

cognitive scores [7], while those who live in them have reported sleeping an average of 46 min longer each night [8] and enjoy better indoor air quality [9]. The supporting factors that have transformed the more sustainable building industry include the green building rating systems, the most popular and well-known of which is the U.S. Green Building Council's Leadership in Energy and Environmental Design (USGBC LEED) [1,2,10]. By the end of 2019, over 146,400 projects had been registered with LEED [11]. By providing technical guides to help users balance environmental protection, energy performance, and financial benefits, LEED promotes these values in its building projects [1,2,12,13]. In addition, green building projects often gain additional financial support as a result of policies that create further advantages for developers working on green building projects [14].

Although following the LEED requirements brings many benefits for both the project's design performance and its community value, compliance with these requirements does add to the cost (1–9%) and is often challenging for the project team [1,2,10,15]. These challenges include a more complicated design process that involves many additional field cooperation requests, limited budgets, and the need to comply with the LEED construction document requirements [2,16]. To address these issues and improve the overall performance of the building design stage, an investigation of the green strategies that will be incorporated at an early stage of the integrated design process has been recommended by the USGBC and other experts [2,13,17]. During this period, the project team needs to orient and evaluate the design, future construction, and operation plan for the project based on the framework of nine LEED categories and the various credits they contain [10]. After meeting the requirements of the chosen credits, points are awarded for those achieved for each LEED criterion; the appropriate certification level (Platinum, Gold, Silver, Certified, or noncertified) is then be awarded based on the total points achieved [17]. The wide variety of credits/strategies and the flexibility of LEED creates many options for project teams developing sustainable buildings [18], so selecting the most appropriate target LEED credits out of the various options is an essential yet challenging problem for LEED project managers who are also juggling limited budgets, tight project schedules, and factors associated with the unique location and climatic characteristics of their building site [19]. Not surprisingly, there have been a number of studies suggesting methods to support those making these decisions at an early stage in the process when these decisions will have the greatest impact [13,20]. However, challenges remain due to a lack of information/understanding, the high level of expert collaboration required, and the time and cost limitations typically experienced in the early project phase. The increased cost can also become an issue, depending on the project manager's previous experience with similar projects and his or her level of commitment during project implementation [1,2]. Several studies have investigated the achieved LEED credits from past certified projects, offering insights and helpful suggestions for LEED project managers [15,21]. Studying data on achieved LEED credits from previous certified projects may also provide useful input for future projects [1,22]. However, the significant updates of the technical requirements in LEED v4 have created a gap in the application of previous studies' results to the current projects that need to be fulfilled. Therefore, this study analyzed data from LEED-certified buildings to create a practical guide to help project developers identify the most appropriate LEED credits for their projects at an early stage in the process. Our main objectives were to (1) rank the various LEED credits awarded based on their popularity, (2) investigate the differences in the achieved credits for each of the LEED project levels, and (3) measure the association between the LEED credits in v4. The results of this analysis of actual project data also enabled us to re-evaluate the impact of the new LEED v4 framework in the light of the goals set for this updated version by the USGBC.

2. The Different Needs in the LEED V4 Projects

LEED New Construction version 4 (LEED-NC-V4), referred to as LEED v4, is the latest update to the code. There are several important differences between the processes involved in implementing a traditional project and a LEED project, so applying a conventional management process to a LEED project could require implementing costly modifications at a late stage in the design process as well as increased costs in the building's operation upon entering service because of lack of optimization of the

various building systems [2]. As a result, an integrated design process can be highly beneficial for LEED projects as this builds greater cooperation among project teams to achieve a high-performance green design with a minimal increase in costs [17]. The LEED project management process follows the same phases as the traditional design procedure but incorporates activities that are essential for an integrated design approach [2]. In the predesign stage, the project team is required to collect information, conduct a preliminary assessment, establish a LEED target, and create a roadmap for LEED certification. They then move on to the early design stage, which involves the integration of green building principles, strategies, and products into the design using the LEED-NC credits as a guiding framework to ensure that the building is optimized and firmly on the path to achieving certification. The LEED credit framework influences decisions related to the envelope and the choice of HVAC systems, materials, and lighting. The final stage of the LEED project management process includes activities that are integral to the successful implementation of green construction practices on-site, such as construction waste recycling and air quality management. To achieve better cost-effectiveness, the LEED tasks, including project goal setting, targeted credits, design optimizing, and LEED site planning, should be done during the predesign and design phases, as all must be completed before the beginning of the construction phase. This is why the early identification of project objectives and criteria/strategies credits dramatically influences the ultimate success of the project.

Identifying the LEED project goals with the optimum combination of appropriate criteria/strategies will have a significant impact on project costs, schedules, and even project administration and contracts [2]. Many previous studies have therefore focused on identifying ways to improve the investment performance of LEED projects using a variety of methods. A popular approach has been to apply green building information modeling (green BIM), where research on BIM technical achievements has been highly effective in supporting the design of energy-efficient buildings and minimizing the resources required to measure credits. In recent years, although green BIM studies have produced valuable results [9,23–25], most have focused on building performance modeling, primarily energy, thermal, and lighting simulations [9,23,26–29], all of which require the collection of a great deal of design information and are thus costly to apply in the early project phase [1]. A number of other problems with the BIM approach have also been identified, including poorly defined business goals [24], application of the wrong BIM level of development, and excessive regulation [25].

Another common approach has been to apply better project management techniques. These studies aim to improve the coordination among project team members by providing guidelines or building on previous experience [13,30,31]. These studies suggest that approaches such as an integrated design process (IDP), construction management at risk, or design building are particularly well suited to LEED projects because they encourage early cooperation between stakeholders.

Other studies have analyzed previously collected data using statistical methods, data mining, or data mining techniques, taking advantage of these resources to build a foundation for predictions and recommendations for future LEED projects. The results of these analyses can also be useful for assessing the effectiveness of new and updated policies from the USGBC. Most of these studies have focused on the selection of LEED certificates with different factors [1,10,32–36] and the correlational relationships between credits [19,22,37], and their results can be usefully applied in the early phase of a project where copious information is not yet available [1] and for providing an overview to guide developers' decision-making processes and the policy decisions made by the regulatory authorities. As yet, however, these studies have only analyzed a limited number of attributes (LEED credits) and old data sources from projects implementing previous LEED versions. The current version of LEED, LEED New Construction version 4 (LEED-NC-V4), which replaces LEED 2009 for all newly registered projects, has been significantly updated, and several new credits have been added [1,32]. This has created a considerable gap for those seeking to apply the findings of the previous studies to new projects. Previous studies also did not perform a comprehensive analysis that encompassed all the credits, thus failing to provide sufficiently detailed information to enable the project team to fully consider all the available options. A study that investigates all the credits that could potentially be

awarded in LEED v4 projects is thus necessary to fill this gap and supply useful additional support for project teams.

The major changes introduced in LEED v4 consist of the addition of several new criterion groups, an expansion of the prerequisites and credits, and the requirements for some credits [1,32,38]. The LEED for New Construction and Major Renovations (LEED-NC) v4 has two extra categories that were not in the previous version, namely, "integrative process" (IP) and "location and transportation" (LT). LEED v4 now has 12 prerequisites (up from 8) and 43 credits (down from 49); some parts of the healthcare and education criteria have been altered slightly, and the demonstration requirements for the credits in the material category are significantly different. A more detailed review of the differences between LEED v4 and LEED 2009 is available in the USGBC's Summary of Changes document [38].

3. Research Methods

3.1. Data Collection

The study population consists of all the LEED-NC v4 projects certified up to the end of March 2020 [32]. Of the 3108 registered LEED-NC v4 projects, only 222 were actually LEED-certified by the USGBC by this date. Similar to previous studies, LEED project data, including location, date of certification, and certification level, were collected from the USGBC's website (https://www.usgbc.org/projects) or the Green Building Information Gateway (GBIG) (http://www.gbig.org). The purpose of the study was to investigate the LEED-NC v4 awarded credits for existing completed buildings that had achieved certification to identify data that could be useful for project design groups selecting appropriate credits for future projects early in the design process. Our ultimate aim was to develop a set of suggestions to help guide project teams as they make decisions regarding which green strategies and optional LEED credits would be most cost-effective for their particular project. The data collected covered all 42 credits in eight main criteria; the implementation of the prerequisite credits was not examined, as all projects that receive certification can be assumed to have fulfilled these satisfactorily [17]. Regional priority credits were also not included in the analysis because these could not be controlled by the project team or the developer.

3.2. Data Analysis

The Mean-Value Ranking test, Kolmogorov–Smirnov test, one-sample *t*-test, Mann–Whitney *U*-test, nonparametric effect size index, and association rules analysis were employed in the analysis (Table 1). In order to compare the performances of the 42 LEED credits and eight LEED categories, the first step was to calculate the percentage of average score (PAS) as a credit frequency indicator [10,35]. The PAS for each credit was calculated in terms of the points obtained (PO) divided by the total points (TP) expressed as a percentage, as the name suggests:

$$\text{PAS} = \frac{\text{PO}}{\text{TP}} \times 100\% \tag{1}$$

The means and standard deviations (SD) of the PAS for each of the LEED-certified projects were calculated, and the credits ranked in descending order of popularity based on the mean value; the standard deviations were compared if two credits had the same mean value. Next, the Kolmogorov–Smirnov test was applied to examine the normality of the collected data based on the following null hypothesis:

Hypothesis 1 (H1). *There is no significant difference between the data and a normal distribution.*

Where there was a significant difference between the data collected and a normal distribution, a one-sample *t*-test was used for the groups with more than 30 samples [39]. To investigate the credits that achieved significance, a one-sample *t*-test for the null hypothesis (H1: the frequency of awarded

credit is more than 50%) and a confidence index of 95% was conducted. Because the archived LEED credits are presented using ordinal scales, and the number of samples to be compared exceeds 9 [32], a nonparametric approximate Wilcoxon–Mann–Whitney (WMW) test was used to determine the significant difference between two adjacent certification level groups. Pseudoreplication [40] was also considered, so Cliff's δ (Equation (2)) and WMW tests were used to identify differences in the credits achieved by the two unpaired groups.

$$\delta \ = \ \#(x_1 > x_2) - \frac{\#(x_1 < x_2)}{n_1 \times n_2} \tag{2}$$

Table 1. The analytical methods used in the study.

Purpose	Method	Software	References
To determine the order of the accessible LEED v4 credits.	Mean/SD-Value Ranking	MS Excel	[10,34,35]
To test the normality of the data.	Kolmogorov–Smirnov test	SPSS 20.0	[1,10,40–42]
To determine whether the credits are significantly achieved.	One-sample *t*-test	SPSS 20.0	[1,40–42]
To compare the two unpaired groups and conduct a sacrificial pseudoreplication analysis.	Wilcoxon–Mann–Whitney	SPSS 20.0	[1,10,42]
	Cliff's δ & neo-Fisherian	MS Excel	[1,40,42]
To assess the achievement of two related credits.	Association rules analysis	R	[19,22,41]

Finally, the signs and magnitudes of the statistical effects were interpreted based on neo-Fisherian significance assessments (NFSAs). Precise *p*-values were evaluated and classified as either negative, suspended, or positive. Finally, association rule mining, a well-known method utilized in civil engineering and construction to discover interesting relationships between variables in construction field data, was applied to explore the relationships between the various LEED-NC v4 credits. Here, the information collected for the data attributes was first transformed into a binary form (0 or 1) to render it suitable for the association rules analysis. A set of rules was then defined in the form A→B, where A represents the previousness and B the subsequentness [41]. To select a rule of interest from all the possible rule sets, constraints on various measures of importance and interest were used, including the "support," "confidence," and "lift" (Equations (3)–(5), respectively) [19].

$$\text{Support}(A \rightarrow B) \ = \ P(A \cap B), \tag{3}$$

$$\text{Confidence}(A \rightarrow B) \ = \ P(B/A), \tag{4}$$

$$\text{Lift}(A \rightarrow B) \ = \ \frac{P(B/A)}{P(B)} \ = \ \frac{P(A \cap B)}{P(B).P(B)}. \tag{5}$$

Here, support is the probability of co-occurrence and confidence is the conditional probability of B given A; lift indicates how much stronger the relationship between A and B is compared with the probability that A and B trade together by chance. An association rule is considered to be generated when the lift is one or more, and the minimum confidence criterion is exceeded for the rules satisfying the minimum support threshold.

4. Results

The PAS means, standard deviations, and results of the Kolmogorov–Smirnov test and one-sample *t*-test are presented in Table 2. As the Kolmogorov–Smirnov test results confirmed that the data collected displayed significant differences with a normal distribution, the one-sample *t*-test was only performed for the sample as a whole (number of samples > 30) in the next step; the results are also presented in Table 2. A one-sample *t*-test was conducted to identify the significantly awarded credits

at LEED projects with a comparative value of 50% and a confidence index of 95%. The results of the one-sample *t*-test and PAS mean value showed that the following credits (see the Appendix A for a list) were significantly achieved in the LEED v4 projects: INc2 (LEED accredited professional), IEQc3 (construction IAQ management plan), LTc2 (credit sensitive land protection), MRc5 (construction and demolition waste management), WEc1 (outdoor water use reduction), WEc4 (water metering), SSc5 (heat island reduction), SSc1 (site assessment), INc1 (innovation), WEc2 (indoor water use reduction), IEQc1 (enhanced IAQ strategies), EAc2 (optimize energy performance), LTc7 (credit reduced parking footprint), IPc1 (integrative process), EAc3 (advanced energy metering), SSc6 (light pollution reduction), SSc3 (open space), LTc8 (credit green vehicles), and EAc1 (enhanced commissioning). Perhaps not surprisingly, the most popular awarded credits (CAD > 80%) were those with the lowest cost [1], including policy-related credits such as INc2 (LEED accredited professional), IEQc3 (construction IAQ management plan), LTc2 (sensitive land protection), and MRc5 (construction and demolition waste management), as well as those related to water efficiencies, such as WEc4 (water metering) and WEc1 (outdoor water use reduction). In particular, the fact that LTc1 (neighborhood development location) credits have a zero PAS value suggests that as currently implemented, the USGBC's LEED Neighborhood Development program is not achieving the desired results.

To award and encourage more effort of green building developers, the USGBC provides four levels of LEED certification: LEED Certified, LEED Silver, LEED Gold, and LEED Platinum [1]. LEED Gold and LEED Platinum bring a significantly greater market value [43], but also require greater investment from developers as they involve a more complex design/construction to satisfy the requirements of the higher certification levels. This led us to investigate the choices made by developers faced with this decision, focusing on a comparison of the credit allocations between projects achieving two adjacent LEED levels utilizing the results of the Wilcoxon–Mann–Whitney (WMW) test and Cliff's delta values (Table 3). The results for the first group, comparing LEED Certificate and LEED Silver projects ($n = 50$), indicate that LEED Silver projects generally have nine more credits than those at the certificate level, namely, INc1 (innovation), LTc4 (credit surrounding density and diverse uses), EAc3 (advanced energy metering), IEQc1 (enhanced IAQ strategies), IEQc3 (construction IAQ management plan), IPc1 (integrative process), SSc1 (site assessment), SSc3 (open space), and SSc4 (rainwater management). Only the INc1 credit has a medium effect size difference, however, which suggests that innovative solutions are seldom achieved in the LEED Certified projects. Comparing the results for the LEED Silver and LEED Gold projects, the LEED Gold projects implemented 14 additional credits, namely, LTc3 (credit high priority site), LTc4 (credit surrounding density and diverse uses), LTc5 (credit access to quality transit), LTc6 (credit bicycle facilities), LTc7 (credit reduced parking footprint), LTc8 (credit green vehicles), WEc3 (cooling tower water use), WEc2 (indoor water use reduction), EAc1 (enhanced commissioning), EAc5 (renewable energy production), EAc2 (optimize energy performance), MRc1 (building life-cycle impact reduction), INc1 (innovation), and SSc3 (open space). In particular, the LTc4 (surrounding density and diverse uses) and LTc5 (access to quality transit) credits have a medium effect size difference; both of these credits are usually achieved when the project is located in an urban area with high population density and many surrounding services. This suggests that project location factors have a major effect on achieving LEED Gold or LEED Platinum certification. For the highest-level comparison, LEED Gold and LEED Platinum projects, the results of the analysis reveal that the LEED Platinum projects achieved additional 14 credits, namely, EAc2 (optimize energy performance), MRc1 (building life-cycle impact reduction), MRc3 (building product disclosure and optimization—sourcing of raw materials), IEQc5 (thermal comfort), IEQc6 (interior lighting), SSc4 (rainwater management), SSc6 (light pollution reduction), EAc1 (enhanced commissioning), EAc3 (advanced energy metering), EAc5 (renewable energy production), EAc7 (green power and carbon offsets), INc1 (innovation), WEc1 (outdoor water use reduction), and WEc2 (indoor water use reduction). Of these, MRc1 (building life-cycle impact reduction), MRc3 (building product disclosure and optimization—sourcing of raw materials), IEQc6 (interior lighting), SSc4 (rainwater management), IEQc5 (thermal comfort), EAc7 (green power and carbon offsets), EAc1 (enhanced commissioning), and EAc4 (enhanced refrigerant

management) credits had a medium effect size, and EAc7 (green power and carbon offsets) had a large effect size. This indicates that the indoor air quality and relevant materials credits were only popular among those implementing LEED Platinum projects. The LEED Platinum certified projects also had outstanding energy savings compared with the other certificate levels of LEED. The on-site renewable energy option is often considered as the last points in LEED Platinum projects only. It is also interesting to note the additional effort needed to move up from the LEED Gold to LEED Platinum certificate; the 20-point difference between these two groups is twice that of the other transitions, where the difference is only 10 points.

Table 2. Credit popularity ranking and the results for the Shapiro–Wilk normality and one-sample *t*-tests.

PAS↓ (%)	Credit ID	Avg. Point	SD	Sig. KS-Test	*p*-Value *t*-Test	PAS↓ (%)	Credit ID	Avg. Point	SD	Sig. KS-Test	*p*-Value *t*-Test
97.7	INc2	0.98	14.87	0.000 [a]	0.000 [b]	49.1	LTc6	0.49	50.10	0.000 [a]	0.789
90.1	EQc3	0.90	29.95	0.000 [a]	0.000 [b]	48.2	LTc5	2.41	44.90	0.000 [a]	0.550
86.9	LTc2	0.87	33.78	0.000 [a]	0.000 [b]	47.5	EQc6	0.95	34.70	0.000 [a]	0.289
86.0	MRc5	1.72	30.21	0.000 [a]	0.000 [b]	45.0	EQc8	0.45	49.87	0.000 [a]	0.140
83.6	WEc1	1.67	24.48	0.000 [a]	0.000 [b]	43.4	EAc5	1.30	46.86	0.000 [a]	0.037 [b]
80.2	WEc4	0.80	39.95	0.000 [a]	0.000 [b]	42.3	EQc5	0.42	49.52	0.000 [a]	0.022 [b]
77.6	RP	0.78	25.43	0.000 [a]	0.000 [b]	36.6	SSc4	1.10	46.70	0.000 [a]	0.000 [b]
73.6	SSc5	1.47	42.46	0.000 [a]	0.000 [b]	34.5	IEQc4	0.69	37.99	0.000 [a]	0.000 [b]
71.6	SSc1	0.72	45.19	0.000 [a]	0.000 [b]	32.2	EAc7	0.64	45.98	0.000 [a]	0.000 [b]
71.0	INc1	3.55	27.41	0.000 [a]	0.000 [b]	29.6	IEQc2	0.89	36.86	0.000 [a]	0.000 [b]
70.9	WEc2	4.26	28.33	0.000 [a]	0.000 [b]	24.8	SSc2	0.50	42.48	0.000 [a]	0.000 [b]
69.1	IEQc1	1.38	37.22	0.000 [a]	0.000 [b]	22.3	Mrc1	1.11	32.35	0.000 [a]	0.000 [b]
68.2	EAc2	12.28	25.94	0.000 [a]	0.000 [b]	21.6	Mrc2	0.43	25.28	0.000 [a]	0.000 [b]
68.0	LTc7	0.68	46.75	0.000 [a]	0.000 [b]	20.5	WEc3	0.41	38.60	0.000 [a]	0.000 [b]
59.9	IPc1	0.60	49.12	0.000 [a]	0.003 [b]	19.8	LTc3	0.40	35.45	0.000 [a]	0.000 [b]
59.9	EAc3	0.60	49.12	0.000 [a]	0.003 [b]	14.9	IEQc7	0.45	26.99	0.000 [a]	0.000 [b]
58.1	SSc6	0.58	49.45	0.000 [a]	0.015 [b]	14.9	Mrc3	0.30	25.70	0.000 [a]	0.000 [b]
57.2	SSc3	0.57	49.59	0.000 [a]	0.031 [b]	12.4	Mrc4	0.25	23.15	0.000 [a]	0.000 [b]
56.8	LTc8	0.57	49.65	0.000 [a]	0.044 [b]	7.9	EAc4	0.16	23.18	0.000 [a]	0.000 [b]
56.5	EAc1	3.39	33.27	0.000 [a]	0.004 [b]	3.6	IEQc9	0.04	18.68	0.000 [a]	0.000 [b]
51.4	LTc4	2.57	39.28	0.000 [a]	0.585	0.0	LTc1	0.00	0.00	-	-
51.4	EAc6	0.51	50.09	0.000 [a]	0.688	-	-	-	-	-	-

[a] Significance < 0.05; hence the null hypothesis (H1) of the Shapiro–Wilk normality test was rejected. [b] *p*-value < 0.05; hence the null hypothesis (H1) of the one-sample *t*-test was rejected. -: Significance and *p*-value cannot be calculated because the standard deviation is 0.

The results of the association rule mining (Table 4) revealed 442 strong association rules that exceeded the minimum support threshold of 0.4 and reliability = 0.7. Arranging these in order of "support" and "confidence," eight rules were chosen by eliminating rules with a lift value of less than 1. Among these, the most important was the participation of a LEED Accredited Professional (AP) in the project (INc2), which affected the results of the credits IEQc3 (construction IAQ management plan), LTc2 (sensitive land protection), and MRc5 (construction and demolition waste management). This highlights the important role played by LEED experts in contributing to the management of sustainable site planning and activities during the construction phase. The credits for LTc2 (sensitive land protection) and MRc5 (construction and demolition waste management) also affected the INc1 groundbreaking reward. The credits LTc2 (indirectly) and IEQc3 (indirectly) also contributed to the points awarded for innovation. Site management credits such as IEQc3 (construction IAQ management plan) and MRc5 (construction and demolition waste management) also affected each other, along with the WEc2 credit (indoor water use reduction). A whole commissioning process, which included

the EAc1 (enhanced commissioning) credit, also brings better efficiency for WEc1 (outdoor water use reduction). Having a better management plan can explain this, as the assistance of a LEED AP facilitates efforts to collect and document the evidence required by LEED during the development process. These results also show the influence of the LEED AP on the implementation of LEED credits, especially when planning the site management.

Table 3. The results of the Wilcoxon–Mann–Whitney (WMW) test and Cliff's delta indexes between adjacent pairs of Leadership in Energy and Environmental Design (LEED) certificate levels.

ID	Sig. WMW	Cliff's Delta	Effect Size	NFSAs	ID	Sig. WMW	Cliff's Delta	Effect Size	NFSAs
a. LEED-Certified and LEED Silver (n = 50)									
INc1	0	−0.379	Medium	Positive	SSc3	0.017	−0.19	Small	Positive
LTc4	0.004	−0.3	Small	Positive	SSc4	0.013	−0.185	Small	Positive
EAc3	0.018	−0.252	Small	Positive	IEQc3	0.004	−0.179	Small	Positive
IEQc1	0.049	−0.247	Small	Positive	SSc1	0.027	−0.173	Small	Positive
IPc1	0.015	−0.191	Small	Positive	IPc1	0.015	−0.191	Small	Positive
b. LEED Silver and LEED Gold (n = 67)									
LTc4	0	−0.415	Medium	Positive	EAc5	0.002	−0.212	Small	Positive
LTc5	0	−0.369	Medium	Positive	Mrc1	0.018	−0.2	Small	Positive
LTc8	0	−0.281	Small	Positive	INc1	0.009	−0.194	Small	Positive
LTc6	0.004	−0.247	Small	Positive	LTc7	0.029	−0.183	Small	Positive
WEc3	0.001	−0.244	Small	Positive	LTc3	0.023	−0.182	Small	Positive
EAc1	0.026	−0.234	Small	Positive	EAc2	0.03	−0.178	Small	Positive
WEc2	0.022	−0.224	Small	Positive	SSc3	0.024	−0.16	Small	Positive
c. LEED Gold and LEED Platinum (n = 24)									
EAc2	0	−0.591	Large	Positive	EAc1	0.009	−0.351	Medium	Positive
Mrc1	0.003	−0.442	Medium	Positive	EAc5	0.002	−0.348	Medium	Positive
Mrc3	0.002	−0.438	Medium	Positive	SSc6	0.03	−0.283	Small	Positive
IEQc6	0.001	−0.433	Medium	Positive	INc1	0	−0.279	Small	Positive
SSc4	0.001	−0.424	Medium	Positive	EAc3	0.004	−0.248	Small	Positive
IEQc5	0.004	−0.404	Medium	Positive	WEc1	0.016	−0.246	Small	Positive
EAc7	0	−0.377	Medium	Positive	WEc2	0.005	−0.232	Small	Positive

Table 4. The results of the association rule mining.

No.	Rules			Support	Confidence
	lhs/rhs **	↔ *	rhs/lhs		
1	MRc5	↔	INc2	0.901	0.98
2	IEQc3	↔	INc2	0.883	0.98
3	IEQc3	↔	WEc2	0.878	0.975
4	EAc1	↔	WEc1	0.806	0.994
5	LTc2	↔	INc2	0.86	0.99
6	IEQc3	↔	INc1	0.869	0.965
7	IEQc3	↔	MRc5	0.847	0.94
8	LTc2	↔	INc1	0.838	0.964

* ↔: LEED credits with 2-way association. ** The lhs (left-hand side) and rhs (right-hand side) of the rule.

5. Discussion

5.1. Setting a LEED Certification Target and Points

There is a note that most project point totals tend to cluster in groups just above the threshold of the target levels for both LEED 2009 and LEED v4. For example, LEED Silver projects generally achieve a total of around 52 points, just 2 points above the threshold for the Silver level. It seems likely

that project teams like to implement a couple of contingent credits to ensure they achieve the project's target certification level, holding an average of 2 to 3 points in reserve based on previous projects.

5.2. Priority Project's Studies of High-Frequency Credits

Based on the findings of this research study, we can make the following recommendations to the project team (developer, designer, and LEED managers). First, an integrated design process should be implemented at the outset to ensure the LEED goals for the project are established at the predesign stage in order to make the best use of the investment funds and ensure the success of the project. Two or three reserve LEED points should be included to provide a safety margin and make sure that the project meets the target level of certification. The most commonly used credits for the desired rating level should be considered to maximize the project's feasibility. The most widely used credits for the projects surveyed for this study consisted of the project's innovativeness (INc1, 3.55 points), construction IAQ management plan (IEQc3, 0.90 point), protection of sensitive land (LTc2, 0.87 point), careful construction and demolition waste management (MRc5, 1.72 points), outdoor water use reduction (WEc1, 1.67 points), water metering (WEc4, 0.80 point), minimizing of contribution to the urban heat island effect (SSc5, 1.47 points), thorough site assessment to identify potential problems before construction begins (SSc1, 0.72 point), indoor water use reduction (WEc2, 4.26 points), monitoring of the outdoor air delivery (IEQc1, 1.38 points), optimizing of the building's energy performance (EAc2, 12.28 points), reduction of the parking footprint (LTc7, 0.68 point), utilization of an integrative process from the outset (IPc1, 0.60 point), advanced energy metering (EAc3, 0.60 point), reduction of light pollution (SSc6, 0.58 points), provision of open space for the building's occupants to enjoy (SSc3, 0.57 point), facilities for electric vehicles (LTc8, 0.57 point), and utilization of enhanced commissioning procedures (EAc1, 3.39 points).

For LEED Silver or higher projects, innovation (INc1) solutions are implemented explicitly, as well as additional credits, such as supporting greater density and diverse uses (LTc4), advanced energy metering (EAc3), and implementing demand response (EAc1). Projects located in a high-density area (meeting the requirements of both the high-density (LTc4) and quality transit (LTc5) credits) were especially helpful for obtaining LEED Gold or higher certification. Other credits that should be considered to achieve LEED Gold certification include facilities for electric vehicles and bicycles and reduced parking footprint (LTc6, LTc7, and LTc8, respectively), reducing indoor water use and cooling tower water use (WEc2 and WEc3), utilizing enhanced commissioning, optimizing energy performance and renewable energy production (EAc1, EAc2, and EAc5, respectively), reducing the building's life-cycle impact, using an innovative design on a high-priority site, and incorporating open space (MRc1, INc1, LTc3, and SSc3, respectively).

For the highest level of LEED certification, reducing the building's life-cycle impact and conducting a comprehensive product disclosure and optimization exercise (MRc1 and MRc3), providing efficient indoor lighting and thermal comfort (IEQc6 and IEQc5), managing rainwater (SSc4), enhanced commissioning, and renewable energy, and green power (EAc1, EAc5, and EAc7, respectively) were all strongly recommended for LEED Platinum projects. Additional credits for items such as light pollution reduction (SSc6), innovation (INc1), energy metering system (EAc3), and high-efficiency water performance equipment (WEc1 and WEc2) must also be considered to help the project achieve the highest LEED certification level.

5.3. Achieved Categories Were Changed Compared with Previous Versions

In the last few years, several pieces of research on the selection of LEED credits have been conducted. However, most of the available studies have differences from the purpose of finding achieved categories of the study, such as using the data of LEED version 2.2, LEED adaptations [19,34], or sample regions [1,32,35,37,42], or not considered [21,22,40,41]. Therefore, the adherence rate for the main LEED criteria groups is shown in Table 5. Comparing the results with those reported in an earlier study [10] that collected similar data for the previous LEED implementation, LEED 2009, there has been

a significant shift in the tendency to select the various criteria groups. Although the thresholds are now higher for the various criteria designed to reduce and optimize energy usage, all the criteria related to the operation costs of buildings such as water and energy efficiency have higher achievement rates in projects built to meet the new standards. Compared with the previous analysis [10], the achievement rates for criteria in the "energy and atmosphere" standards increased by 16.6%, rising from 40.3% for LEED 2009 to 56.9% for LEED v4. "Water efficiency" also increased, rising from 60.80% to 64.58%. This may be either because the technologies now available deliver higher electricity efficiency and lower water consumption, or due to the growing public awareness of the depletion of these limited resources. Interestingly, achievement levels for two of the groups, "materials and resources" and "indoor environmental quality," are markedly lower for LEED v4 than for LEED 2009, which may be due to the difficulty of satisfying the new more stringent standards. The achieved high rate (77.59%) of the regional priority credit (RP) showed the success of the regional priority program in efforts to promote green buildings to new areas by balancing location advantages.

Table 5. Comparison of the distribution trends for the main criteria in LEED 2009 and LEED v4.

Main Criteria in LEED v4	LEED 2009 (July 2015) *			LEED v4 (March 2020)			
	Max Points	Achieved Rates	Ranking	Max Points	Average Points	Achieved Rates	Ranking
Integrative process (IP)		Not applicable		1.00	0.60	59.91%	3
Location and transportation (LT)		Sustainable sites		16.00	7.99	49.92%	6 ↓
Sustainable sites (SS)	26	61.00%	2	10.00	4.94	49.37%	7 ↓
Water efficiency (WE)	10	60.80%	3	11.00	7.10	64.58%	2 ↑
Energy and atmosphere (EA)	35	40.30%	5	33.00	18.78	56.90%	5 ↑
Material and resources (MR)	14	38.70%	6	13.00	3.81	29.31%	9 ↓
Indoor environmental quality (IEQ)	15	59.10%	4	16.00	6.19	38.66%	8 ↓
Regional priority (RP) credits	4	**	-	4.00	3.10	77.59%	1
Innovation (IN)	6	67.80%	1	6.00	3.55	59.16%	4 ↓
Total	110	**	-	110.00	57.16	-	-

* Data from [10]. ** Data not provided in the previous studies.

6. Conclusions

One of the major contributions of this study is bridging the gap between LEED 2009 and LEED v4 by analyzing how the new standards are functioning in practice and updating the guidance provided to project managers, enabling them to identify the most appropriate and achievable credits for their project at an early stage of the development process. To develop these recommendations, in this study we (1) identified the most commonly achieved credits and innovation for each accreditation level and (2) highlighted the differences in the credits implemented on either side of the dividing lines between LEED certification levels and (3) the association rules for the LEED credits obtained. These results provide useful information for project teams and developers seeking to identify the most appropriate LEED goals for their project, enabling them to quickly assess the most feasible credits/strategies they can utilize to help them achieve their project's objectives. In particular, these results show how useful it is to involve a LEED AP in the planning process and not just to supervise the implementation of the LEED credits related to site management once the construction phase is underway.

According to the LEED v4 summary report issued by the USGBC [38], LEED v4 is more tightly focused on encouraging a performance-based approach to design. The results of the study support this, as certified-LEED v4 projects achieved higher efficiencies for both energy and water consumption. The USGBC stresses that LEED v4 is not just about updating the technical standards to take into account the latest technological innovations; it also aims to support more flexible strategies to fit the unique aspects of individual projects. However, the data collected for LEED-certified projects did reveal an imbalance between the compliance rates for the main LEED criteria. Although the impact on human health and the environment due to the choice of construction materials has led to an expanded focus on the materials criteria in LEED v4, the compliance rates for the credits belonging to these two groups of criteria (IAQ and MR) are significantly below those achieved by projects achieving certification

under LEED 2009. This suggests that most current project teams have not yet fully adapted to the new requirements for materials and indoor air quality credits, indicating a need for the USGBC and LEED experts to introduce additional training to support the implementation of these criteria among project teams. Local governments could also help by adopting policy measures that support green material manufacturers.

This study suffers from some limitations, the most important of which is our inability to analyze other LEED sectors because of the limited data available, which also had an adverse effect on the results of this study. Thus, we recommend that further studies should be conducted once the data pool is large enough to provide better support in identifying the most appropriate credits for different types of LEED projects and thus provide a more nuanced analysis. A comprehensive review of the global data will require the collection of much more extensive data to enable researchers to conduct detailed studies in different parts of the world that will provide invaluable information on the strategies that will be needed to cope with differences in microclimates and local conditions.

Appendix A. LEED NC-v4 Rating Systems and Credits Mentioned in This Paper

Table A1. Rating Systems: LEED BD+C: Building Design and Construction. Source: https://leeduser.buildinggreen.com/.

The ID	Description	Max Points
IPc1	Integrative process	1
LT Total	**Location and Transportation**	**32**
LTc1	LEED for neighborhood development location	16
LTc2	Credit sensitive land protection	1
LTc3	Credit high priority site	2
LTc4	Credit surrounding density and diverse uses	5
LTc5	Credit access to quality transit	5
LTc6	Credit bicycle facilities	1
LTc7	Credit reduced parking footprint	1
LTc8	Credit green vehicles	1
SS Total	**Sustainable Sites**	**10**
SSc1	Site assessment	1
SSc2	Site development—protect or restore habitat	2
SSc3	Open space	1
SSc4	Rainwater management	3
SSc5	Heat island reduction	2
SSc6	Light pollution reduction	1
WE Total	**Water Efficiency**	
Wc1	Outdoor water use reduction	2
Wc2	Indoor water use reduction	6
Wc3	Cooling tower water use	2
Wc4	Water metering	1

Table A1. *Cont.*

The ID	Description	Max Points
EA Total	**Energy and Atmosphere**	
EAc1	Enhanced commissioning	6
EAc2	Optimize energy performance	18
EAc3	Advanced energy metering	1
EAc4	Demand response	2
EAc5	Renewable energy production	3
EAc6	Enhanced refrigerant management	1
EAc7	Green power and carbon offsets	2
MR Total	**Material and Resources**	
Mrc1	Building life-cycle impact reduction	5
Mrc2	Building product disclosure and optimization—EPD	2
Mrc3	Building product disclosure and optimization–sourcing of raw materials	2
Mrc4	Building product disclosure and optimization–material ingredients	2
Mrc5	Construction and demolition waste management	2
IEQ Total	**Indoor Environmental Quality**	
IEQc1	Enhanced IAQ strategies	2
IEQc2	Low-emitting materials	3
IEQc3	Construction IAQ management plan	1
IEQc4	IAQ assessment	2
IEQc5	Thermal comfort	1
IEQc6	Interior lighting	2
IEQc7	Daylight	3
IEQc8	Quality views	1
IEQc9	Acoustic performance	1
RP Total	**Regional Priority Credits**	**1**
IN Total	**Innovation**	
INc1	Innovation	5
INc2	LEED accredited professional	1
Total		**110**

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