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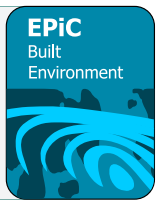

Identifying the Leading Credit Categories in Determining the Overall LEED NC Score of Multifamily Residential Projects

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Leadership in Energy and Environmental Design (LEED) has been the focus of several studies due to being globally accepted as a standard for the design, construction, and operation of highly efficient buildings. However, less research has focused on specific project types and the credit allocation of LEED systems in these projects. This research evaluates the associations between the scores achieved by multifamily residential projects in each category of LEED BD+C for New Construction version 4 (LEED-NC v4) and the overall LEED score of the projects to understand the consistency between the anticipated and actual weight of each category in determining overall sustainability of the projects. Data about the LEED-certified projects was gathered from the U.S. Green Building Council website and was analyzed through a multiple regression analysis. The results showed some consistencies and some discrepancies between the anticipated and actual weight of credit categories. For instance, Indoor Environmental Quality showed a higher influence on overall LEED score compared to Location and Transportation, despite having a lower weight in the system. These findings underscore the importance of periodically reviewing and revising the LEED criteria based on past projects and involving stakeholders in the development of the standards for this system.

Key Words: LEED NC v4, Credit Category, Green Building, Multifamily Residential Projects

Introduction

Green building rating systems are formulated to analyze the overall life cycle efficiency of the built environment. Among these systems, the Leadership in Energy and Environmental Design (LEED), established by the U.S. Green Building Council, stands out as the widely adopted system globally and within the United States (Wu & Low, 2010). Buildings that have received LEED certification are known as projects with enhanced environmental efficiency, including lower energy usage, reduced carbon emissions, and lower operational expenses (Chan, Qian, & Lam, 2009).
The LEED for New Construction (LEED NC) is the prevailing rating system among LEED systems and concentrates on the construction of new buildings and major renovations. In the United States,

there are more than 16,400 projects that have received LEED NC certification to date. LEED NC has several versions each version has updates and changes compared to the previous ones. Developed in 2013, LEED version 4 made significant changes to its predecessor, LEED v2009. Although this version, like the previous version (LEED v2009), includes 110 points in total, it has added a new category that accounts for one possible point (Integrative Process - IP). Other changes such as reducing the number of potential credits of the Sustainable Sites category from 26 to 10 and allocating the remaining credits as well as new credits to a new category of Location and Transportation with 20 credits were also made in this version. Furthermore, the number of credits in the Water Efficiency category has increased in LEED-NCv4 introducing additional criteria concerning the preservation of water consumed in cooling towers and the implementation of a metering system for monitoring water consumption. In this version, the Energy and Atmosphere category has decreased in number of credits from 35 to 33 while the weight for enhanced commissioning credit has increased. Another important change that was made in LEED NC v4 was that the Materials and Resources category incorporated novel requirements based on life cycle assessments of the projects. Lastly, the Indoor Environmental Quality category added one new credit to the previous version making 16 total credits in this category (Pushkar, 2020).

As LEED is accepted as a global standard for designing, building, and operating high-performance green buildings and communities, several studies have been conducted about multiple aspects of this system (e.g. Goodarzi & Berghorn, 2022, 2024). For instance, Da Silva and Ruwanpura (2009) investigated the LEED credits earned by some buildings in Canada and discovered that the categories of Materials and Resources and Energy and Atmosphere had the least amount of credit achievement. Ma and Cheng (2016) investigated the attainment of individual credits in past LEED-certified projects, revealing that certain credits, such as rapidly renewable materials and material reuse were seldom obtained. Goodarzi et al. (2023) evaluated the consistency between the weight given to each credit category in LEED NC version 3 and the actual weight of those categories in defining the sustainability level of certified projects. In a similar study, Goodarzi and Shayesteh (2024) investigated the practicality of LEED NC version 4 in terms of the weight allocation to the differen credit categories. Both studies found inconsistencies between the expected and actual effects of some categories and suggested further studies on this topic by taking into account the effect of project type on the relationship between credit categories and overall LEED score.

Consequently, the focus of this study is narrowed to multifamily residential projects, thereby addressing the limitations mentioned in the author's preceding research. More specifically, this paper aims to: (1) examine the relationships between the LEED NC v4 credit categories and the overall LEED scores achieved by multifamily residential projects; (2) evaluate the relative importance of each credit category by contrasting its assigned weight with its actual influence on the overall sustainability score; and (3) provide enhancement suggestions for the future versions of LEED NC system, drawing on historical project data that provides valuable insights for refining credit allocation in future system updates.

Method

Data Collection

In order to collect data from the USGBC website, all the projects having LEED-NC certification in the United States were listed and then filtered by the version. The target projects in this study are multifamily residential projects that are certified under LEED-NC version 4. After filtering the

projects by version, the projects that were certified under version 4 were listed making a total of 1023 projects. These projects were then classified based on the project type and only multifamily residential projects were selected for this study making a total of 104 projects that were certified under this system by November 1, 2022. After the first screening of the projects, 21 projects were found to have different types, such as senior living or student housing, despite being listed as multifamily residential projects. Therefore, those projects were removed from the data and the retained 83 projects were considered for the data analysis. Next, a box plot was conducted for each variable to find and remove outliers followed by Cook's Distance test of residuals to detect the influentials. As a result, 8 projects were removed from the data either for being outliers or having a Cook's Distance of f greater than 0.05, and 75 projects were retained for further data analysis.

Data Analysis

In this study, the dependent variable was the projects' overall LEED NC scores and the predictors were the credit categories of the LEED NC v4 system including "Location and Transportation" (LT), "Sustainable Sites" (SS), Indoor Environmental Quality" (IEQ), "Materials and Resources" (MR), "Energy and Atmosphere" (EA), and "Water Efficiency" (WE). The analysis method in this study was multiple regression analysis (MLR) to evaluate the relationships between the predictors and the response variable and understand whether the expected effect of each credit category on the overall sustainability of the projects is in line with its actual effect. To come up with unbiased and accurate results, the data first should meet the assumptions of the test. Therefore, the MLR assumptions were first tested. To conduct the data analysis, Jasp version 18 was used as the analysis software.

Multiple Regression Assumption Test

The MLR assumptions are lack of multicollinearity, normality of residuals, the linear relationships between each predictor and the response variable, homoscedasticity, and independence of errors (Osborne & Waters, 2002; Uyanık & Güler, 2013).

A scatterplot of the standardized residuals and the dependent variable was investigated to test the homoscedasticity and linear relationship assumptions. The scatterplot shown in Figure 1 indicates linear relationships between variables as well as a lack of homoscedasticity due to a lack of any clear pattern in the residuals' distribution.

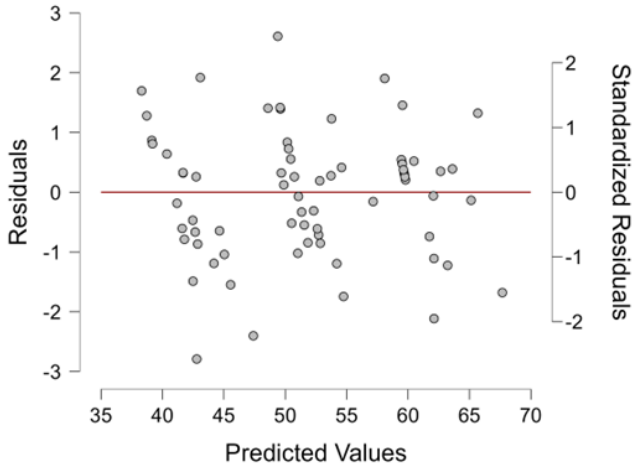

Figure 1. Residuals plot

Next, a Shapiro-Wilk test was conducted to test the normality of residuals (Table 1). This test hypothesizes that the residuals are normally distributed and if the null hypothesis is not rejected, it can be concluded that the distribution of the data is normal. As the computed p-value is greater than the significance level (alpha=0.05), one cannot reject the null hypothesis and therefore, the residuals are normally distributed. This can also be seen in the histogram of residuals (Figure 2).

Table 1

The normality of residuals (Shapiro-Wilk test)

W	0.991
p-value (Two-tailed)	0.870
alpha	0.050

A Durbin-Watson test was then conducted to test the independence of errors (Table 2). The value of 2.049 indicates that there is no autocorrelation between the residuals. It is worth mentioning that if the Durbin-Watson value falls between 1.5 and 2.5, the autocorrelation does not exist between the residuals. The ideal number for this statistic is 2.00 and the closer the results are to this number, the chance of autocorrelation between the residuals is lower.

Table 2

Durbin-Watson Test Results

Autocorrelation	Statistic	p
0.163	2.049	0.883

Lastly, the collinearity of the variables was tested through an analysis of Tolerance and the Variance Inflation Factor (VIF). The results shown in Table 3 indicate that there is no multicollinearity among the independent variables by all these variables having a VIF of smaller than 10 and a Tolerance of greater than 0.1.

Table 3

Multicollinearity Test Results

	LT	SS	WE	EA	MR	IEQ
Tolerance	0.930	0.844	0.853	0.916	0.916	0.837
VIF	1.076	1.185	1.172	1.092	1.091	1.194

Multiple Linear Regression Analysis

After testing the assumptions, it was evident that the data met all the assumptions. Therefore, the next step was to conduct the MLR to evaluate the relationships between the credit categories and the overall LEED NC score of the multifamily residential projects that are certified under the LEED NC v4 system. Table 4 shows the descriptive statistics of the data.

Table 4

Descriptives

	N	Mean	SD	SE
LEED-Overall	75	51.773	7.955	0.919
LT	75	11.520	3.090	0.357
SS	75	4.648	1.983	0.229
WE	75	5.733	1.473	0.170
EA	75	11.973	3.983	0.460
MR	75	4.171	1.516	0.175
IEQ	75	5.893	2.380	0.275

The model summary shown in Table 5 demonstrates that the amount of variance in the LEED NC overall score that is explained by the six independent variables (credit categories) is 96% ($R^2 = .962$). An R^2 of greater than 0.7 shows that the data fits the model and that the model is explaining the changes in the dependent variable.

Table 5

Model Summary

Model	R	R^2	Adjusted R^2	RMSE
H_0	0.000	0.000	0.000	7.955
H_1	0.981	0.962	0.959	1.618

The results of the analysis of variance (ANOVA), as shown in Table 6, illustrate that the variance between the model mean and the LEED NC overall score was statistically significant (DF= 6; F= 286.887, pValue<0.001). In other words, given the p-value of the F statistic computed in the ANOVA table, and given the significance level of 5%, the information brought by the explanatory variables is significantly better than what a basic mean would bring.

Table 6

ANOVA

Model		Sum of Squares	df	Mean Square	F	p
H_1	Regression	4505.172	6	750.862	286.887	< .001
	Residual	177.975	68	2.617		
	Total	4683.147	74			

Note. The intercept model is omitted, as no meaningful information can be shown.

Finally, the relationships between independent and dependent variables were evaluated by conducting a standardized coefficient analysis. Table 7 shows the results of this analysis. These results help understand the actual effect of each credit category on the overall LEED NC score achieved by multifamily residential projects. The results of this test indicated that the EA category has the strongest association with the overall LEED NC score, with the IEQ category, LT category, SS category, and WE category following in descending order of strength. Additionally, the results highlight that the MR category has the weakest association with the overall LEED NC score of the projects.

Table 7

Coefficients

Model		Unstandardized	Standard Error	Standardized	t	p
H_0	(Intercept)	51.773	0.919		56.362	< .001
H_1	(Intercept)	1.687	1.348		1.252	0.215
	LT/20	1.099	0.063	0.427	17.415	< .001
	SS/10	1.109	0.103	0.276	10.742	< .001
	WE/11	1.232	0.138	0.228	8.916	< .001
	EA/33	1.036	0.049	0.518	20.990	< .001
	MR/13	1.047	0.130	0.199	8.074	< .001
	IEQ/16	1.433	0.086	0.429	16.595	< .001

Discussion

This study evaluated the relationships between the LEED NC v4 credit categories and the overall LEED NC score of the multifamily residential projects that have achieved LEED NC certification by November 1, 2023. This evaluation was conducted to understand whether the weight given to each credit category by the Green Building Certification Institute is realistic and practical when compared

to the points achieved by the projects. The findings of the study illustrated that among all the credit categories that were studied, the Energy and Atmosphere category is the most influential category in achieving the overall LEED NC score for multifamily residential projects. As this category has the highest weight in the LEED NC system by accounting for 33 points out of 110 overall LEED NC scores, it was anticipated that it would have the highest effect on achieving sustainability by the studied projects. This finding shows the consistency between the achievability of the the credits under this category and the weight given to this credit category thus demonstrating the development of realistic and practical criteria for achieving sustainability through meeting Energy and Atmosphere requirements and credits.

The second category that showed to have a high effect on achieving LEED NC v4 certification by multifamily residential projects was Indoor Environmental Quality. This category accounts for 16 points out of 110 total achievable credits by the projects and is the third largest category in this LEED NC system. Being the second influential category was not anticipated by this category because it ranks third among the credit categories of this LEED NC system after Location and Transportation, which accounts for 20 credits. This discrepancy between the points achieved by the LEED-certified projects and the weight given to these two categories demonstrates a lack of realistic weighting criteria for some categories and highlights that the LEED standards should be reviewed periodically and use the lessons learned from the existing certified projects. This finding also highlights that projects tend to achieve indoor environmental quality because it is directly understandable by the users of the buildings and it can also be a selling point for the projects if they are successful in achieving high standards in this category. This finding contrasts with the findings of Goodarzi et al. (2023) showing that Indoor Environmental Quality was the least influential category in determining the overall LEED NC score of university residence halls.

Another surprising finding of this study was that the Sustainable Sites credit category was the fourth influential category followed by Water Efficiency and Material and Resources. It was anticipated that Material and Resources would be the fourth most influential category as it accounts for 13 points, which makes it higher than Water Efficiency (11 points) and Sustainable Sites (10 points). However, the results show otherwise, and the order of effect is opposite among these three categories with Sustainable Sites showing higher effects on achieving the overall LEED NC score compared to Water Efficiency and Material and Resources. Although this finding might demonstrate a lack of practicality and comprehensiveness in the development of the LEED NC criteria, other variables might also affect the achievement or failure to achieve some of the credits such as the pandemic and the issues associated with it including supply chain issues, material availability, labor availability, price escalation, etc. Therefore, it is necessary to conduct other studies to find the most likely reasons behind these findings.

The discrepancies discussed in this study highlight the need for further studies on the effects of different credit categories on achieving sustainability certification by the projects. It also demonstrates that opportunities for achieving some of the credits are higher than others. The findings show that achieving some credit categories might be more desirable for the projects because the project stakeholders might think that those credits add more value to the projects. Another important factor that can affect the achievement of the credits is the cost associated with meeting the requirements of those credits. It is important to consider the role of cost in the correlation of points to overall LEED NC scores because some points might be more costly to achieve thus being less desirable for developers to consider. Therefore, these considerations should be taken when analyzing the actual effect of each credit on achieving the overall LEED NC score. However, even if cost is an important obstacle to achieving some of the credits, it should be considered in the development of the criteria and assigning weights to each credit to motivate practitioners to seek to achieve those credits. This is

possible only by involving project stakeholders in the decision-making and engaging them in developing the sustainability criteria for this system.

Conclusion

This study analyzed the relationships between the main credit categories of the LEED NC v4 system, and the overall LEED score achieved by multifamily residential projects that are certified under this system. The main goal of the study was to investigate the consistencies between the weight given to each category and the actual effects of those categories in achieving LEED NC certification. The findings were mostly unexpected and showed the need for reconsideration of the criteria for some credits and further deliberation with project stakeholders and users in developing and weighting the certification criteria.

Although the study evaluated all the multifamily residential projects that were certified by the date, the number of the projects was still low, and this is one of the limitations of this study. Therefore, this evaluation should be conducted again in the future as well as for the other project types to come up with more generalizable findings. This limitation suggests that future studies should be conducted to evaluate a larger group of LEED-certified projects and compare the findings with this study. Other aspects such as the cost of achieving certain credits as well as some external factors that affect the availability of materials and resources should also be considered in future studies.

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