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Empirical evaluation of the LEED green building rating system: exploring limitations through configurational analysis

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ABSTRACT

The Leadership in Energy and Environmental Design (LEED) rating system faces critical methodological shortcomings that limit its ability to drive holistic sustainability. This study explored these shortcomings through a configurational analysis of 1248 LEED-certified buildings in the US, identifying combinations of LEED categories that contribute to high ratings. Configurational analysis revealed five distinct pathways to achieving high green building (GB) performance outcomes and obtaining LEED certification. The results indicated that three out of nine LEED categories are consistently present across all five configurations, whereas four categories are underutilized in the certification process. To enhance the effectiveness of LEED, this article proposed three targeted reforms to strengthen the evaluative rigour of LEED. First, addressing overlaps among credits would ensure that awarded points reflect genuine sustainability contributions. Second, introducing minimum score thresholds for underutilized categories would promote a more balanced approach. Third, integrating region-specific benchmarks would align certification criteria with local environmental priorities and climate conditions, making GB standards more responsive to regional sustainability challenges. This study enhances understanding of how different LEED categories interact to influence sustainability outcomes. In addition, by refining LEED's methodological foundations, it contributes to the evolution of a more rigorous, equitable and region-sensitive GB certification system.

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Configurational analysis; credit achievement degree; fuzzy set qualitative comparative analysis; green buildings; LEED rating system

Introduction

Over the past three decades, there has been a growing recognition of the significant environmental and energy-related impacts of buildings. Buildings account for a critical share of global energy consumption and contribute substantially to CO_2 emissions (Guerin, 2024). Concerns about the adverse environmental effects of traditional building practices have driven the building sector towards more efficient resource and energy use. Concurrently, there has been an increased emphasis on enhancing the social sustainability of buildings (Kjeldsen & Stender, 2022).

These developments have catalysed a shift towards green buildings (GBs), where sustainable practices are integrated into the design, construction and operation of buildings to reduce their environmental footprint while improving social and health outcomes. This shift requires countries and jurisdictions to develop and implement control mechanisms to regulate and promote sustainable practices in the built environment (Ismaeel, 2019). As a result, various GB rating systems have been developed to enhance energy efficiency, health and overall sustainability in buildings (Cole & Valdebenito, 2013).

One widely adopted rating system is Leadership in Energy and Environmental Design (LEED), which was first introduced by the United States Green Building Council (USGBC) in 1998 with version 1.0 (Lee, 2013). As of February 2025, LEED has expanded its application to 186 countries worldwide (Kaplow, 2024). The LEED rating system has been praised in both research and practice for broadening the traditional focus of rating systems on energy efficiency only to include social dimensions such as public health and social cohesion. This broader perspective has inspired the development of numerous frameworks to facilitate the implementation of LEED and increase its global adoption (Gluszak et al., 2021; Santana et al., 2023).

Despite its pivotal role in advancing GB agendas, LEED has faced significant criticism in the literature. Specifically, LEED has been criticized for its predominantly globalized framework, which fails to fully account for regional differences in environmental

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conditions, regulatory requirements and climatic variations (Boschmann & Gabriel, 2013). Some argue that this lack of region-sensitive benchmarks diminishes its effectiveness as a sustainability tool (Ade & Rehm, 2020). Furthermore, research has highlighted dissatisfaction among occupants of LEED-certified buildings, particularly concerning the quality of the indoor environment, which is a key category assessed by the LEED system (Altomonte et al., 2019).

While the limitations of the LEED rating system have been widely documented in the literature, the primary focus of such research has been on its outcomes and external impacts. However, excepting only few studies (e.g. Ismaeel, 2019; Ismaeel & Ali, 2020), little attention has been given to critically examining the methodological foundations of the LEED rating system itself, leaving a significant gap in understanding of its internal mechanisms and potential areas for refinement. Recognizing this shortfall, recent studies have emphasized the need for research aimed at enhancing the methodological rigour of green certification systems (Espinoza-Zambrano et al., 2024). Responding to this call, the present study aims to address this gap by analysing the methodological characteristics of the LEED rating system, identifying its inherent weaknesses and proposing pathways for improvement.

To achieve this, the article analysed empirical data from 1248 newly constructed buildings in the US and employed fuzzy set qualitative comparative analysis (fsQCA) – a widely used tool for configurational analysis – to identify the combinations of LEED categories that lead to high ratings. Through this approach, this article pinpointed the LEED categories that must be present to achieve a high score, as well as complementary categories that interact synergistically with other categories to yield a high score. By distinguishing these categories, this article identified critical categories that, despite their significance, are underemphasized or entirely overlooked in the LEED rating system. Based on these insights, this article proposed targeted areas for improvement in the LEED rating system, including refining its evaluation criteria and incorporating overlooked categories to create a more robust and comprehensive framework for GB assessment.

This article is the first to use configurational analysis to investigate the limitations of the LEED rating system. As a result, it contributes to the GB literature by highlighting the methodological advantages of configurational analysis in identifying the synergies among various LEED categories that result in high ratings for GBs. This approach overcomes the limitations of traditional correlation and regression methods (e.g. structural equation modelling), which analyse each category in isolation and overlook the complex, non-linear relationships between LEED categories and their combined effect on high ratings. By utilizing configurational analysis, this study enhances understanding of how different categories of LEED interact to influence sustainability outcomes, providing a solid framework for future research and practice in GB certification.

Literature review

Overview of LEED rating system

Since its inception in 1999 (USGBC, 2013), LEED has been periodically updated to expand its scope and refine its criteria. The development of LEED certification progressed from the first version, LEED v1, through successive versions, culminating in LEED v4, which was released in 2013 (USGBC, 2013). The most recent version, LEED v5, is slated for full implementation following the USGBC ballot process in 2025 (Moumouni et al., 2024). LEED v5 introduces significant structural changes, particularly to the Material and Resources (MR) category. However, limited adoption and project data restrict its ability to perform in-depth analysis. Thus, this research uses the more established LEED v4 to leverage its widespread application and mature dataset.

In the LEED v4 rating system, buildings are assessed based on their performance in nine key categories. Each category includes specific credits, representing points that buildings can earn by meeting sustainability criteria. The total points accumulated across all categories determine the building's overall rating, which in turn dictates its certification level.

LEED v4 has four certification levels based on total points earned: Certified (40–49 points); Silver (50–59 points); Gold (60–79 points); and Platinum (80 points or more; USGBC, 2019). Buildings that meet the minimum threshold receive a Certified rating, while those achieving the highest scores earn the prestigious Platinum certification. This structured scoring system ensures a standardized assessment of sustainability performance, encouraging higher levels of environmental efficiency in the design and construction of buildings.

Prior research on LEED rating system

LEED is widely acknowledged as a practical and influential rating system for assessing the sustainability and environmental performance of GBs. While its origins are rooted in practice, academic interest in LEED emerged as early as the 1990s, with initial studies focusing on its market application (Crawley & Aho, 1999).

Over time, the scope of LEED-related research has significantly expanded, aiming to refine the rating system and boost its adoption. The review of LEED-related literature presented in this article identifies five primary research streams that reflect the diverse ways scholars have engaged with LEED.

The first research stream explores how the LEED rating system assists in achieving the targeted objectives of GBs, including environmental performance, health, wellbeing and sustainable material selection (Ismaeel, 2023). Within this body of research, studies have evaluated various LEED credits and categories, mainly in isolation from other credits and categories, with an emphasis on developing frameworks for better building performance, evaluation or decision-making. Specifically, this stream has examined how various evaluation criteria, including categories and credits, drive improvements in GB performance. For example, researchers have explored occupant satisfaction (Altomonte et al., 2019); daylighting (Wilder et al., 2019); energy performance (Chen et al., 2015); water efficiency (Lynch & Dietsch, 2010); and transportation (Chen & Nguyen, 2017) in LEED-certified buildings.

The second research stream focuses on the use and development of technology to assist with LEED certification. Studies within this stream primarily focus on developing advanced techniques and tools to enhance the analysis of sustainable projects and support more effective decision-making. Within this stream, researchers have explored the integration of various technologies with LEED certification to support decision-making and optimize sustainable outcomes and cost efficiency (Abdallah et al., 2016; Marzouk et al., 2018). These technologies include building information modelling (BIM; Marzouk et al., 2018); Web Map Service (Chen & Nguyen, 2019); and automated decision support systems (Alshamrani & Alshibani, 2020).

The third stream examines performance gaps, that is, the differences between a building's anticipated and actual performance. Within this stream, post-occupancy evaluation has been instrumental in assessing how LEED-certified buildings perform compared with non-certified buildings (Li et al., 2022). Case studies have further highlighted the variations between expected and realized sustainability outcomes (Zang et al., 2022). In addition, studies within this stream have examined the relationship between LEED certification levels and the actual environmental performance of certified buildings, shedding light on the effectiveness of the rating system in achieving sustainability goals (Greer et al., 2019).

The fourth research stream performs cross-comparisons between LEED certification and other GB certification systems, such as building research establishment environmental assessment method (BREEAM) and Green Star. These comparisons have evaluated various dimensions, including energy use assessment (Lee & Burnett, 2008); regional adoption and usage patterns (Cole & Valdebenito, 2013); the capability of each system to assess sustainability performance (Seinre et al., 2014); and the comprehensiveness of the certification criteria in evaluating project sustainability performance (Lee, 2013). These comparisons provide insights into the relative strengths, limitations and regional adaptability of different certification systems, highlighting opportunities for improving sustainability evaluation frameworks.

The fifth research stream emphasizes the analysis of scores achieved in the LEED rating system, referred to as credit achievement degree (CAD). Such studies have shed light on the relative ease or complexity of achieving specific LEED credits and categories. Studies within this stream provide comparative analysis of credits, identifying those that are more frequently targeted by LEED-certified projects and those that are less commonly achieved – known as underutilized credits. The analyses conducted in these studies provide valuable insights into achievement patterns, revealing how they vary based on geographic and regional factors (e.g. climate, environmental priorities, regulatory requirements); project types and sectors (e.g. office, education, industrial, residential); economic and institutional factors (e.g. gross domestic product, legislative frameworks, number of accredited professionals); project-specific characteristics (e.g. size, certification level, owner priorities and team expertise); and temporal factors (e.g. year of implementation). Such studies have also provided practical recommendations for increasing the adoption of underutilized credits (Ismaeel, 2019; Wu et al., 2016; Wu et al., 2017). Key recommendations from these studies include reforming the credit allocation system to better align points with actual environmental impact and address systematic underutilization of certain categories, particularly in relation to the use of materials and resources in GBs (Wu et al., 2017). Studies also recommend incorporating regional adaptation mechanisms to account for local climate conditions and environmental priorities rather than applying uniform global standards in every context (Ismaeel, 2019). In addition, multiple studies emphasize the need to address practitioners' perceptions of cost and complexity barriers that influence credit adoption patterns, particularly for energy-related credits (Lavy & Fernández-Solis, 2009; Wu et al., 2017).

Despite the extensive body of research examining the outcomes and external impacts of the LEED rating system, significant gaps persist in understanding its internal methodological foundations. While most studies focus on LEED's effectiveness in promoting energy efficiency and social sustainability or comparing its performance with other rating systems, limited attention has been given to critically examining the combination of categories within the LEED rating system that contributes to high building ratings. Understanding these category combinations is important for identifying how buildings achieve high ratings, which is often by prioritizing certain categories while neglecting others – an imbalance that could compromise the long-term sustainability of GBs. To address this gap in understanding, this article employs configurational analysis of LEED categories to uncover the specific combinations of these categories that drive high building ratings with the aim of highlighting potential category imbalances and identifying areas that may be overlooked in achieving sustainable outcomes.

Synopsis of configurational analysis

Configurational analysis offers a framework for exploring complex phenomena by examining how different combinations of conditions interact to produce desired outcomes. Unlike traditional linear methods (e.g. multiple regression analysis) that rely on uniform and reductionist assumptions, the configurational analysis approach embraces equifinality – the notion that multiple pathways can lead to similar results (Marcon et al., 2024). Grounded in configurational theory, configurational analysis is particularly well suited for examining causally complex issues, such as achieving high-performing GBs.

Among the methods used to implement configurational analysis, fsQCA has gained prominence for its ability to blend qualitative richness with quantitative precision (Homayouni et al., 2021). This method investigates complex causal relationships by integrating qualitative insights and quantitative analysis (Huarng & Yu, 2024). Unlike conventional statistical techniques that typically assess the net effects of individual variables on an outcome, fsQCA leverages configurational theory to address phenomena characterized by causal complexity, equifinality and asymmetry (Chen et al., 2024). The strength of fsQCA lies in its configurational perspective, which facilitates theoretical advancements and practical applications. Its versatility is evident in its application across diverse fields to address complex research questions, for example, building research (Van der Heijden, 2015); project management (Wu et al., 2024); and organizational psychology (Lyngstadaas & Berg, 2024).

The use of configurational analysis is particularly well suited to the present research because it offers a robust framework for analysing the interdependencies among key LEED categories. By distinguishing necessary and complementary categories, this approach uncovers minimally sufficient combinations that drive high GB ratings. These findings provide valuable insights into the gaps within the LEED rating system, enabling the development of targeted recommendations for its improvement.

Empirical data

Data source

This article examined a sample of 1248 newly constructed buildings in the US that qualify for LEED certification under LEED v4. While LEED v5 introduces structural changes to address known systemic issues with LEED categories (Malin & Melton, 2024), the present study focused on LEED v4 for three key reasons. First, LEED v4 represents the established system under which the vast majority of current LEED-certified projects were evaluated, providing a mature dataset of 1248 buildings for comprehensive configurational analysis. The limited availability of LEED v5 project data due to its recent release restricts the potential for conducting in-depth empirical analysis at this time. Second, understanding configurational patterns of LEED v4 is essential for evaluating whether changes in LEED v5 effectively address the systematic limitations of LEED v4 identified in our study. Third, although LEED v5 represents the latest advancement in the certification system, it has not introduced substantial changes to LEED v4. The updates are relatively minor, focusing on incremental improvements rather than a fundamental overhaul. These modest adjustments, coupled with the infancy of LEED v5, limit its widespread adoption and therefore the availability of project data for rigorous analysis.

While LEED certification applies to various building types, this study specifically examined the Building Design and Construction (BD + C): New Construction rating system, which covers both new building construction and major renovation (USGBC, 2019). This rating system encompasses a wide range of project types, including commercial buildings (e.g. offices, retail, mixed-use); institutional facilities (e.g. schools, libraries, community centres); high-rise residential buildings (nine stories or more); government structures (e.g. police stations, civic centres); and light industrial buildings.

The dataset was compiled using publicly accessible LEED scorecards collected in January 2025. LEED scorecards are widely recognized as an empirically reliable data source and have been extensively utilized in prior studies (Ismaeel, 2019; Wu et al., 2016). These

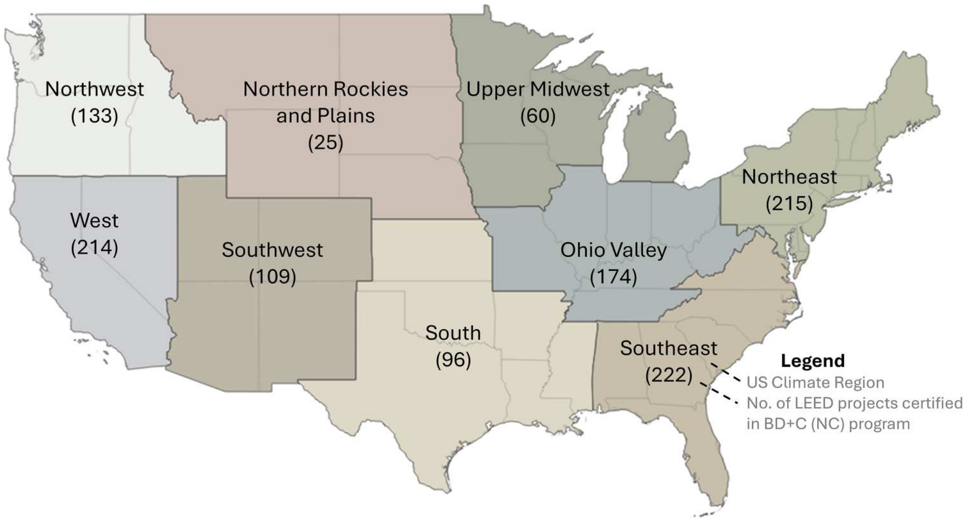

Figure 1. Distribution of buildings in the dataset across nine US climate regions.

scorecards provide standardized and consistent documentation of the credits achieved by each building, enabling objective comparison and in-depth analysis across multiple buildings. Figure 1 illustrates the distribution of the 1248 buildings in the dataset across nine US climate regions, as defined by National Centers for Environmental Information (NCEI) and originally proposed by Karl and Koss (1984).

Variables and measures

The input variables for the configurational analysis are the nine LEED v4 categories (see Table 1; USGBC, 2019). For each category, three key metrics are indicated: (1) the number of available credits that can be pursued; (2) the maximum points achievable within each category; and (3) the relative weight of each category expressed as a percentage of the total possible score.

Table 1. Distribution of LEED v4 credits and scoring weights across nine categories based on LEED v4.

Green building category	Number of credits	Maximum achievable score	Percentage of maximum achievable score
Energy and atmosphere (EA)	8	33	30
Indoor environmental quality (IEQ)	9	16	14.5
Innovation (IN)	2	6	5.5
Integrative process (IP)	1	1	0.9
Location and transportation (LT)	8	16	14.5
Material and resources (MR)	5	13	11.8
Regional priority (RP)	4	4	3.6
Sustainable sites (SS)	6	10	9.1
Water efficiency (WE)	4	11	10

For buildings in the dataset, achievable scores of LEED categories clearly reflect LEED's approach to building assessment. As seen in Table 1, energy and atmosphere (EA) is the category that is most emphasized, comprising 30% of the maximum achievable score with 33 possible credits across eight criteria. The categories indoor environmental quality (IEQ) and location and transportation (LT) follow, each contributing 14.5% of the total score with 16 credits, although they differ in the number of criteria they have (nine and eight, respectively). MR, water efficiency (WE) and sustainable sites (SS) form the middle tier of categories, accounting for 11.8%, 10% and 9.1% of the total score, respectively. In addition, the LEED rating system includes smaller yet significant areas such as innovation (IN; 5.5%); regional priority (RP; 3.6%); and integrative process (IP; 0.9%). This distribution reflects LEED's strong focus on energy efficiency and the quality of the indoor environment while maintaining a comprehensive and balanced approach to sustainable building design.

The output variable of configurational analysis is the overall GB rating of a particular project, which is based on the total score it achieves from the 110 available points (USGBC, 2019). The higher the total LEED score of a building, the higher its GB rating will be.

Method

This article employed fsQCA to identify distinct combinations of LEED categories that lead to high GB performance. Conventional correlation-based methods tend to examine the relationship between a LEED category and a high score by isolating the influence of other categories, often referred to as the 'net effects' estimation approach (Woodside, 2013). However, fsQCA challenges the adequacy of exclusively focusing on whether a LEED category has a positive or negative net effect on achieving a high score, arguing that this perspective can be misleading.

For example, one critical issue with net effects approaches is the presence of asymmetrical relationships between LEED categories and the final rating. Asymmetrical relationships suggest that the influence of LEED categories on the final score may vary depending on the combination of various categories. In such cases, a change in a certain LEED category does not symmetrically affect the final rating (Sharkasi et al., 2025). Traditional correlation-based methods are unable to capture this complexity.

However, it is important to acknowledge certain limitations associated with the fsQCA method. First, there is a lack of theoretical justification for selecting the threshold value for various fsQCA measures (e.g. overall consistency score). To address this, the threshold values suggested by leading and highly cited references such as Pappas et al. (2020) and Woodside (2013) were utilized. Second, fsQCA is ineffective with small sample sizes because it may not generate meaningful configurations with these sample sizes (Liu et al., 2017). This limitation is not applicable to the current study because of the relatively large sample size (1248 LEED-certified buildings) employed.

The fsQCA method follows a systematic three-step process designed to decode the complex and interdependent interactions that drive LEED performance. Figure 2 presents an overview of these steps, outlining their objectives and the corresponding methods employed at each stage. A detailed explanation of each step is presented in the following sections.

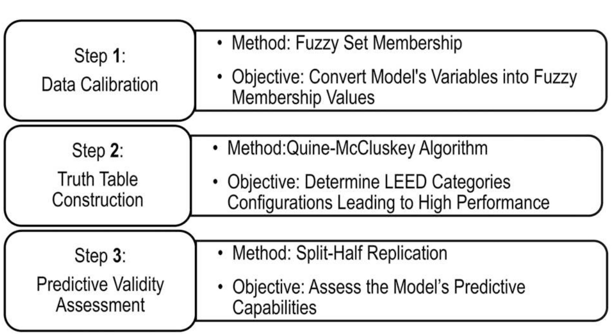

Figure 2. Three-step process for developing and validating the fsQCA model.

Step 1: data calibration

The first step in our fsQCA approach, known as data calibration, involved converting raw numerical data into fuzzy set membership values to enable a nuanced representation of the data that goes beyond traditional correlation-based methods. This approach captures subtle degrees of membership by placing each variable on a continuum ranging from full membership (a score of 1) to full non-membership (a score of 0). Values at the crossover point, with a score of 0.5, indicate partial membership (Pappas et al., 2020).

The calibration process employed three key breakpoints to segment the data into meaningful ranges, allowing for a more refined depiction of how LEED categories contribute to high GB performance. For this study, a quartile-based split of the dataset was applied. For instance, the IEQ category, measured within the domain of [0, 16], was calibrated using the breakpoints 4, 8 and 12, corresponding to full non-membership, the crossover point and full membership, respectively. Similarly, the output variable Green Building Rating was calibrated using breakpoints at 27.5, 55 and 82.5. Table 2 provides a comprehensive summary of the value ranges; input and output variables; and calibration thresholds applied in the configurational analysis.

Step 2: truth table construction

In the second step in fsQCA, a detailed truth table was constructed to determine all possible configurations of LEED categories that lead to high performance. To identify these configurations, the Quine – McCluskey algorithm – a sophisticated optimization technique – was employed (Gupta et al., 2024). This process evaluated the configurations using the consistency metric, which serves to measure the reliability of the identified configurations (Woodside, 2013).

The results of the configurational analysis demonstrated an overall consistency score of 0.9498, significantly exceeding the commonly accepted threshold of

Table 2. Value ranges; input and output variables; and calibration thresholds used in the configurational analysis.

Green building category	Range	Full non-membership	Crossover point	Full membership
EA	[0, 33]	8.25	16.5	24.75
IEQ	[0, 16]	4	8	12
IN	[0, 6]	1.5	3	4.5
IP	[0, 1]	0.25	0.5	0.75
LT	[0, 16]	4	8	12
MR	[0, 13]	3.25	6.5	9.75
RP	[0, 4]	1	2	3
SS	[0, 10]	2.5	5	7.5
WE	[0, 11]	2.75	5.5	8.25
Green building rating	[0, 110]	27.5	55	82.5

Table 3. Results of configurational analysis.

		Configurations				
LEED category	Symbol	1	2	3	4	5
Energy and atmosphere	EA	●	●	●	●	●
Indoor environmental quality	IEQ	⊗	⊗	⊗	●	●
Innovation	IN	●	●	●	●	●
Integrative process	IP		●	●	●	●
Location and transportation	LT	⊗	⊗		⊗	
Material and resources	MR	⊗	⊗	⊗		●
Regional priority	RP	●	●	●	●	●
Sustainable sites	SS	⊗		⊗	●	●
Water efficiency	WE	⊗	⊗	●	●	●
Overall solution consistency				0.9498		

0.75 as recommended in prior research (Ragin, 2008; Woodside, 2013). Five distinct configurations were identified through the analysis, as detailed in Table 3. A solid circle (●) denotes the presence of a condition, while an X-circle (⊗) indicates the absence of a condition. Blank cells represent 'don't care' conditions, where the presence or absence of the condition has no definitive relationship with the desired outcome.

Step 3: predictive validity assessment

The third step in in fsQCA focused on rigorously assessing the model's predictive capabilities by employing the split-half replication method recommended by Pappas et al. (2020). This method entails dividing the dataset into two distinct groups, a subsample and a holdout sample, to evaluate the generalizability of the identified configurations. A total of 624 buildings were randomly excluded from the original dataset to form the holdout sample, with the remaining 624 buildings comprising the subsample.

A configurational analysis was conducted on the subsample to identify the causal conditions linked to high GB performance. This analysis identified three distinct configurations that contribute to achieving a high Green Building Rating. To assess the model's predictive validity, these configurations were tested on a holdout sample. To further validate the model's robustness, fuzzy XY plots were generated, revealing consistent results for both the subsample and the holdout sample (as illustrated in Figure 3). Notably, the data points are concentrated in the upper-left section of the plots, highlighting the asymmetric relationships between the three configurations and the model output (Green Building Rating). This clustering emphasizes the model's ability to capture complex, nonlinear interactions among conditions.

Results

As presented in Table 3, the configurational analysis identified five distinct pathways to achieving high GB

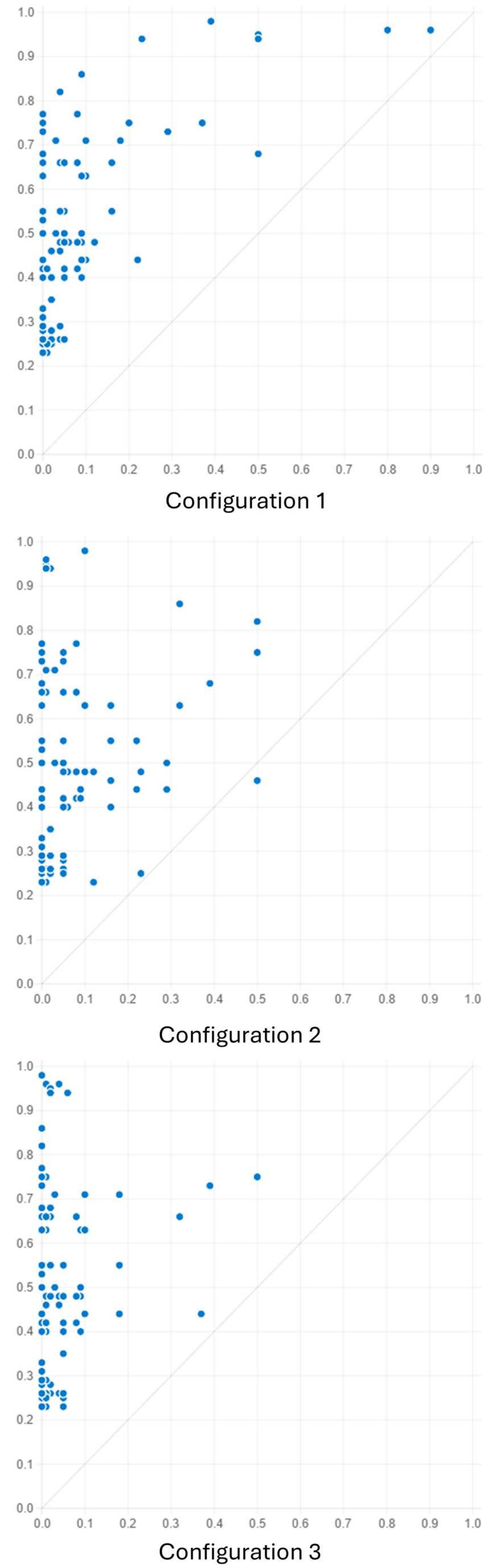

Figure 3. Fuzzy XY plots illustrating asymmetric causal pathways to high Green Building Rating.

performance outcomes and obtaining LEED certification. These pathways illustrated multiple equifinal routes to the desired outcome. The EA, IN and RP categories are consistently present across all five configurations. This consistency underscores these categories as necessary conditions for achieving high GB performance ratings, highlighting their foundational role regardless of the presence or absence of other categories.

Configuration 1 presents an intriguing scenario where high GB performance is achieved despite the absence of five categories: IEQ, LT, MR, SS and WE. This finding suggests that strong performance in EA, IN and RP can effectively compensate for deficiencies in other areas. Configurations 2–5 (Table 3) present evolving patterns of category combinations, offering further insights. For example, IP appears in four of the five configurations, signifying that it is important but not absolutely necessary for achieving high GB performance. Similarly, WE is present in three configurations, also indicating that it is significant but not indispensable in achieving high GB performance.

Categories such as IEQ have varying roles across the configurations. While IEQ is absent in Configurations 2 and 3, it appears in Configurations 4 and 5, suggesting a peripheral role in achieving high GB performance. MR is notably absent in three configurations and present only in Configuration 5, revealing its limited overall importance to GB performance. Similarly, LT is absent in three configurations and neutral in the other two, demonstrating its relatively low impact on GB performance. SS exhibits a similar trend, being absent in two configurations and neutral in another. These findings indicate that buildings have achieved LEED certification despite not attaining high scores in IEQ, MR and SS.

Discussion

Building on prior studies that have used CAD to evaluate and compare LEED performance across categories (Wu et al., 2016; Wu et al., 2017), this section applies CAD analysis to interpret the findings of this research in light of this established metric in the literature. CAD provides a standardized measure for comparing score achievement across different categories, thus facilitating cross-category analysis. CAD is calculated using Equation 1, where CO represents the average score achieved in a given category and TC denotes the maximum possible score for that category.

$$CAD = \frac{CO}{TC} \times 100 \tag{1}$$

Table 4 presents the CAD values for buildings in our dataset, categorized by nine US climate regions. To illustrate how CAD values are derived, consider the IN category: the average score (CO) is 4.8 and the full score (TC) is 6, resulting in a CAD value of 80. As seen in Table 4, MR significantly underperforms compared with the other categories, achieving the lowest CAD value of 41% and ranking last among the nine categories. This is closely followed by the IEQ and LT categories, which are tied at 45% CAD and therefore share the seventh rank. SS performs slightly better, with a CAD of 47%, ranking sixth overall. These findings corroborate the findings of the configurational analysis, which indicate that achieving high GB performance does not require strong performance in all LEED categories. Specifically, the consistently low CAD values for these four categories (i.e. MR, IEQ, LT and SS) reinforce their limited influence in the configurational pathways identified.

Table 4. CAD values and rankings across nine LEED categories.

LEED category	CAD (%)	Rank
Energy and atmosphere	52	4
Indoor environmental quality	45	7 (tied)
Innovation	80	1
Integrative process	57	3
Location and transportation	45	7 (tied)
Material and resources	41	8
Regional priority	66	2
Sustainable sites	47	6
Water efficiency	50	5

These observations highlight a methodological shortcoming of the LEED-certification system, in that it allows buildings to secure high ratings without excelling in categories directly linked to occupant wellbeing, resource efficiency and site sustainability. Furthermore, the configurational patterns identified in this study reflect LEED's inherent difficulty in balancing environmental rigour with market accessibility. While our analysis reveals systematic underutilization of certain categories of LEED as well as gaming behaviours (e.g. point chasing), these outcomes may partially result from LEED's design philosophy being to prioritize broad adoption (or accessibility) over rigour (i.e. stringently meeting environmental performance; Amselem, 2025). For example, the high achievement rates in the IN (80% CAD) and RP (66% CAD) categories may represent conscious choices to incentivize participation and regional engagement rather than attempting to overcome methodological flaws. However, this accessibility-first approach creates the risk that buildings achieve certification without having comprehensive sustainability performance, highlighting the ongoing tension between certification system adoption and environmental effectiveness.

In addition, the results of our configurational analysis align with findings from existing studies on Green Star rating systems. For example, Hoffman et al. (2020) indicated that in South African Green Star projects, the materials and the land use and ecology categories had low average achievement rates of 47% and 37%, respectively. In contrast, the water, transport and energy categories had high achievement rates in Green Star projects. Other than for the transport category, Hoffman et al.'s (2020) findings from Green Star projects are mostly parallel to those of our study. A key difference between our findings relating to LEED projects and Hoffman et al.'s (2020) findings is found for the innovation category. That is, while LEED projects have been found to perform well in the innovation category, Green Star projects in Australia (Xia et al., 2013) and South Africa (Hoffman et al., 2020) were found to have a low achievement in this category. This superior performance of LEED innovation credits is supported by Li et al. (2013), who found that LEED innovation credits are publicly accessible (past approved innovation credits are published online to help project teams develop new innovation credit ideas) and serve as valuable opportunities for contractors to contribute to project teams. In contrast, Li et al. (2013) noted that BREEAM innovation credits are not publicly available, which creates barriers to innovation. This suggests that LEED's more accessible innovation framework may explain the higher achievement rates for LEED observed in our study compared with other rating systems.

Recommendations for overcoming limitations identified in the configurational analysis

Address overlaps among credits

An examination of LEED credits reveals significant overlaps between certain credits in relation to their intended outcomes, which may lead to some redundancies and undermine the methodological rigour of the system. For example, the Rainwater Management credit from the SS category overlaps with the Outdoor Water Use Reduction credit from the WE category because both focus on water management and often employ similar water-efficient landscaping techniques. Similarly, the Optimize Energy Performance credit from the EA category overlaps with the Heat Island Reduction credit from the SS category. This overlap occurs because strategies such as reflective roofing and shading, typically used to mitigate heat islands, also help reduce cooling loads, thus enhancing energy performance. This dual-purpose design approach creates a double-counting effect, where a single initiative (e.g. installing a white roof) can earn points in multiple categories.

While this double-counting effect may enhance accessibility by providing easier pathways to certification, it can encourage a 'point-chasing mentality', where builders prioritize earning easily achievable LEED points rather than implementing effective sustainability measures (Wu et al., 2016). Given that GB certifications enhance marketability, builders often aim to reach a desired certification level with minimal effort. This implies that once the minimum requirements for the desired certification level are met, there is little incentive to earn additional credits (Matisoff et al., 2014; Wu et al., 2017). In addition, the double-counting effect can influence the presence or absence of certain categories across various configurations in configurational analysis, where high or low ratings may not only reflect genuine sustainability efforts (or their absence) but also reveal the result of overlapping credits. This means that some buildings may appear more sustainable than they are, while others might be underestimated because of the uneven allocation of points across multiple categories.

Table 5 provides a detailed overview of these overlaps, along with justifications for their occurrence. These overlaps present significant challenges to the effective evaluation of GBs by inflating the importance of certain strategies that simultaneously influence multiple credits. These findings align with those of Ma and Cheng (2016), who used association rule mining to analyse relationships among LEED credits. Among the various correlations, their study highlighted strong links between heat island reduction (from the SS category) and optimize energy performance (from the EA category), as well as between construction indoor air quality management plan and low-emitting materials (both from the IEQ category). This inflation obscures the precise assessment of the unique contributions of individual credits, thus undermining the methodological rigour of the rating system. Addressing these overlaps would strengthen environmental integrity while requiring careful consideration of how reduced flexibility might affect adoption rates and the overall effect on market transformation.

The credit overlap analysis presented in Table 5 was developed by the authors of this study through a systematic content analysis of LEED v4 credit requirements and implementation strategies. The aim of this analysis was to identify instances where different LEED credits share similar implementation approaches, technologies or outcomes that could potentially lead to double counting of sustainability benefits. The analysis involved the following steps: (1) reviewing the technical requirements and compliance pathways for all LEED credits; (2) identifying credits that share common implementation strategies or

Table 5. LEED credit overlap analysis.

Credit (category)	Overlapping credit(s)	Overlapping features
Rainwater management (SS)	Outdoor water use reduction (WE)	Both focus on water management and often employ similar water-efficient landscaping techniques; the implementation of rainwater management reduces irrigation needs
Heat island reduction (SS)	Optimize energy performance (EA)	Strategies such as reflective roofing and shading used to mitigate heat islands also help reduce cooling loads, thus enhancing energy performance; reflective materials and shading strategies create dual-purpose benefits
Enhanced indoor air quality strategies (IEQ)	Low-emitting materials (IEQ) Construction indoor air quality management plan (IEQ)	All credits target improved indoor air quality through different but overlapping approaches (e.g. source control, construction practices and verification)
Building-level water metering (WE)	Building-level energy metering (EA) Advanced energy metering (EA)	All credits focus on resource consumption monitoring and management systems
Site development – protect or restore habitat (SS)	Outdoor water use reduction (WE)	Habitat restoration often incorporates water-efficient landscaping and natural stormwater management features
Low-emitting materials (IEQ)	Enhanced indoor air quality strategies (IEQ) IAQ Assessment	Source control through material selection overlaps with other indoor air quality management strategies
Advanced energy metering (EA)	Building-level energy metering (EA) Water metering (WE) Enhanced commissioning (EA)	Advanced metering overlaps with basic metering requirements and provides data for commissioning and ongoing verification
Construction indoor air quality management plan (IEQ)	Enhanced IEQ strategies IAQ assessment Low-emitting materials (IEQ)	Construction phase air quality management overlaps with material selection and final verification requirements; strong correlations exist between construction indoor air quality management and low-emitting materials selection
Outdoor water use reduction (WE)	Site development – protect or restore habitat (SS)	Water-efficient landscaping strategies often support both habitat restoration and stormwater management goals

technologies; (3) evaluating the degree of overlap in relation to environmental outcomes and measurement approaches; and (4) documenting the specific mechanisms through which these overlaps occur. This systematic approach enables a more precise understanding of how credit interdependencies can influence the methodological rigour of the LEED rating system.

Prioritizing underutilized categories

The configurational analysis reveals that certain categories – IEQ, LT, MR and SS – are frequently overlooked. A review of buildings in the dataset reveals that a significant number of buildings secured less than 20% of the available scores in these categories (as shown in Table 6).

LT emerges as the most neglected category, with 21.79% of buildings – more than one-fifth of the total – scoring 20% or lower in this category. This is followed by SS, where 15.14% of buildings fall below this threshold. MR and IEQ perform relatively better, with 9.70% and 7.6% of buildings, respectively, scoring 20% or lower in these categories. When examining buildings that completely omitted certain categories (scoring zero), the percentages are relatively low, but they are still cause for concern. SS has the highest omission rate, with 1.36% of buildings ignoring it entirely, followed by LT and MR, each omitted in 1.05% of buildings.

Table 6. Distribution of low-scoring buildings across four LEED categories.

Category	Number and percentage of buildings scoring zero (%)	Number and percentage of buildings scoring 20% or lower (%)
Indoor environmental quality	0 (0%)	95 (7.6%)
Location and transportation	13 (1.05%)	272 (21.79%)
Material and resources	13 (1.05%)	121 (9.70%)
Sustainable sites	17 (1.36%)	189 (15.14%)

This tendency to neglect certain LEED categories can be attributed to the perceived complexity of these categories or the relatively low return of benefits compared with the effort required to implement these categories. The literature has widely recognized this challenge, emphasizing that earning credits in these categories often demands considerable effort (Wu et al., 2016). In addition, studies highlight that reducing the use of essential construction materials such as concrete, cement, steel is highly challenging owing to their fundamental role in any building project. Although cement consumption can be reduced through chemical admixtures, these alternatives are costly and may significantly increase material expenses (Wu et al., 2016; Wu et al., 2017). These higher material costs often prompt developers and builders to explore alternative methods for obtaining LEED credits (Wu et al., 2016). In contrast, innovation-related credits tend to be the easiest credits to obtain (Wu et al., 2016), and this finding is corroborated by our configurational analysis.

To counter this disparity while maintaining market accessibility, the USGBC could introduce incentive mechanisms or create streamlined pathways to promote the adoption of these underutilized credits. In addition, establishing minimum score requirements for each category could prevent buildings from entirely neglecting certain categories, ensuring a more balanced and comprehensive approach to building sustainability. This would eliminate the possibility of buildings scoring zero in any category while promoting equitable progress across all LEED categories. Such measures would not only enhance the accessibility and appeal of these credits but also foster a more holistic commitment to sustainable building practices.

Adopt region-sensitive benchmarks

The USGBC has integrated several regional factors into the LEED rating system to facilitate point achievement in specific categories. For example, the RP category incorporates credits tailored to individual regions, addressing environmental concerns and priorities that vary by geographic location. However, despite these efforts, LEED largely remains a globalized framework in its approach and does not fully account for regional differences in relation to the environment, regulatory environment and climate (Boschmann & Gabriel, 2013). More explicitly, while LEED includes the RP category, which achieved high performance in our analysis (66% CAD, rank 2), this category alone is insufficient to address regional adaptation requirements.

Our empirical analysis demonstrates this limitation: despite RP's availability and high achievement rates, core environmental categories show persistent uniformity across regions. The CAD values for the WE category remain nearly uniform (45%–53%) across regions with vastly different precipitation levels, and performance in the EA category paradoxically shows regions with extreme heat performing worse than those with milder conditions. This suggests that RP's bonus point structure does not drive the differentiated regional performance that would reflect adaptation to local environmental priorities and climate conditions. These findings are supported by earlier studies finding that RP credits do not reflect that a building is addressing the specific environmental problems of different locations (Pushkar, 2018; Wu et al., 2018).

This limitation of the RP category of LEED is clear when comparing the CAD values, discussed in Section 4.5, of various climate regions using regional data on annual precipitation and maximum temperature during summer season. This information was obtained from the official website of NCEI.

Figure 4 presents the annual precipitation levels across US climate regions, while Table 7 reports the CAD values for the WE category across nine climate regions, with the third column indicating the regions' annual precipitation levels from NCEI data. Examining Table 7, it could be expected that regions with lower

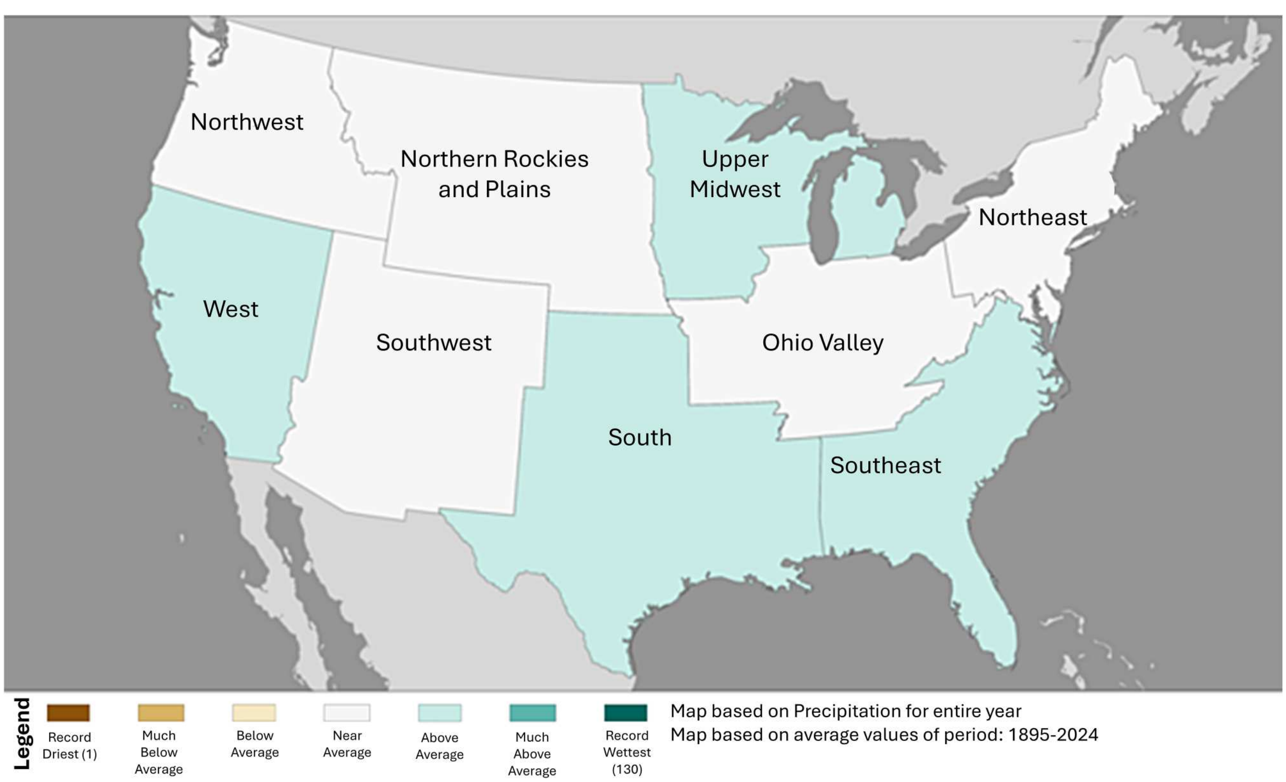

Figure 4. Regional average annual precipitation in the US (source: NCEI).

Table 7. CAD values for the WE category across nine US climate regions.

Region	CAD (WE category)	Annual precipitation
Northeast	52	Below average
Northern rockies and plains	51	Below average
Northwest	48	Below average
Ohio valley	49	Below average
South	50	Above average
Southeast	53	Above average
Southwest	45	Below average
Upper midwest	50	Above average
West	50	Above average

Table 8. CAD values for the EA category across nine US climate regions.

Region	CAD (EA category)	Maximum temperature
Northeast	50	Much above average
Northern rockies and plains	59	Above average
Northwest	49	Much above average
Ohio valley	47	Near average
South	50	Above average
Southeast	47	Above average
Southwest	60	Much above average
Upper midwest	52	Near average
West	62	Much above average

precipitation levels would achieve relatively higher CAD scores in the WE category due to the heightened need for water conservation. However, the analysis reveals near uniformity in CAD values across all regions, indicating that the LEED rating system lacks region-sensitive benchmarks to assess the efficiency of water use. Without accounting for local water scarcity, the LEED rating system fails to incentivize higher water conservation efforts in regions facing drought or dryer conditions.

To further illustrate the lack of region-sensitive benchmarks, regional maximum temperature rankings from the NCEI database were examined. Figure 5 presents the maximum summer temperatures across the nine regions, and Table 8 reports the CAD values for the EA category alongside each region's ranking based on summer temperature.

As seen in Table 8, despite the Northeast and Northwest regions experiencing temperatures that are classified as much above average, their CAD values (50 and 49, respectively) are lower than regions with milder summer temperatures, such as the Northern Rockies and Plains (CAD = 59) and Upper Midwest (CAD = 52). Given that higher temperatures drive greater air-conditioning demand, it could be expected that in regions that experience extreme heat, there would be greater efforts to ensure energy efficiency reflected in their CAD scores. However, the LEED rating system does not adequately account for these regional differences, particularly in the EA category, which is essential for evaluating sustainability outcomes. Consequently, builders do not engage in efforts to ensure greater energy performance in these regions, leading to underinvestment in climate-responsive design features.

These observations are evident in the results of the configurational analysis, particularly in the generation

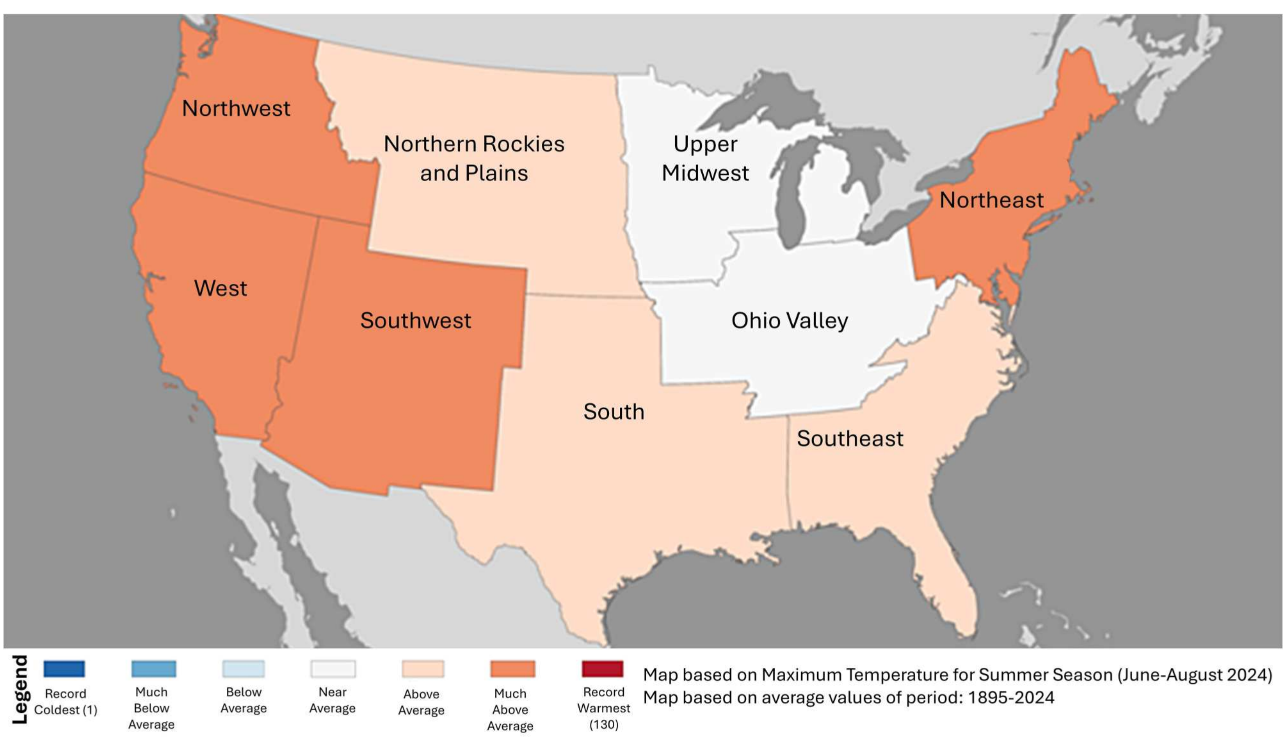

Figure 5. Regional maximum temperature in the US during summer (source: NCEI).

of causal pathways that fail to capture the distinct sustainability challenges of specific regions. The absence of region-sensitive benchmarks in LEED means that the impact of climatic extremes on energy efficiency within the EA category across different climate zones is overlooked by the rating system. As a result, regions with high cooling demands due to extreme summer temperatures are not sufficiently distinguished in their efforts to achieve energy efficiency from regions with milder conditions, masking critical variations that could emerge in a more regionally adaptive set of pathways. Similarly, in the case of water efficiency, the near uniformity in CAD values across regions with differing precipitation levels indicates that LEED's lack of region-sensitive benchmarks limits its ability to reflect local water scarcity. Consequently, drought-prone regions are not clearly distinguished in causal pathways from those with more abundant water resources. This lack of differentiation prevents buildings in drought-prone regions from being properly equipped to save water compared with buildings in regions with more abundant water resources.

To address this limitation, USGBC could adopt region-specific criteria that better align with local climate conditions, building regulations and community needs. Geographic information systems and data analytics could play a critical role in refining these location-sensitive evaluations. The failure of LEED to properly incorporate regional differences in its ranking system means that buildings can gain certification in areas that have particular needs without genuinely addressing these needs. Incorporating regional benchmarks into LEED's rating criteria would enable the USGBC to create a more equitable and effective sustainability framework while maintaining the global standardization that has facilitated LEED's widespread adoption, ensuring that buildings are assessed in alignment with the specific environmental challenges and priorities of their specific locations.

These proposed reforms acknowledge that effective certification system design requires balancing environmental rigour with market accessibility, recognizing that overly proscriptive requirements could reduce adoption rates and thereby diminish LEED's overall contribution to sustainable building practices.

Alignment with LEED v5 developments

The configurational patterns identified in our analysis of the LEED v4 rating system align with the structural changes introduced in LEED v5, suggesting that the observed limitations informed the rating system's evolution. Most notably, our finding that the MR category achieved the lowest CAD (41%) and was consistently absent from configurations directly corresponds to LEED v5's response of implementing a 'major overhaul' of the MR category by making the assessment of embodied carbon from structural materials a prerequisite of this category (Malin & Melton, 2024). Such a change directly addresses the systematic avoidance patterns seen in the projects certified with LEED v4.

In addition, our recommendation for a minimum score threshold aligns with LEED v5's mandatory assessments approach, which is expressed as follows: 'Carbon, climate resilience, and social equity assessments are now prerequisites for every project' (Malin & Melton, 2024). Thus, threshold requirements have been implemented to ensure balanced and genuine sustainability considerations are undertaken in building projects. In addition, our identification of credit overlaps finds partial resolution in LEED v5's credit consolidation efforts, where 'several previous credits' are consolidated 'into one' (Brubaker, 2025). These alignments demonstrate that the present study has provided crucial baseline data for evaluating LEED v5's effectiveness in addressing the configurational limitations identified.

Conclusion

This article employed a configurational analysis of 1248 LEED-certified buildings in the US to uncover critical methodological weaknesses in the LEED rating system, including the neglect of key categories such as IEQ, LT, MR and SS. These categories are frequently overlooked, with a significant proportion of buildings scoring below 20% or even omitting them entirely. Furthermore, the analysis revealed overlaps in credit evaluation, where overlapping criteria allow buildings to earn points in multiple categories for similar sustainability measures, inflating scores without necessarily enhancing environmental or social outcomes. In addition, the lack of region-sensitive benchmarks limits LEED's ability to address regional sustainability challenges effectively.

To address these limitations, the study proposes three targeted recommendations. First, the USGBC should minimize overlaps among credits to ensure that each credit contributes uniquely to sustainability goals. Second, minimum score requirements should be introduced for underutilized categories to prevent buildings from entirely neglecting critical aspects of sustainability. Third, the adoption of region-specific benchmarks would allow LEED to better reflect local environmental priorities and challenges, ensuring that buildings are evaluated in alignment with their geographic and climatic contexts. These measures would enhance the methodological rigour of the LEED system, promoting a more balanced and holistic approach to GB certification.

The findings of this study underscore the importance of refining the LEED rating system to address its methodological shortcomings. By doing so, along with greater engagement with building occupants, the USGBC can ensure that LEED-certified buildings not only achieve high scores but also deliver meaningful sustainability outcomes that benefit both the environment and building occupants. The proposed recommendations provide a pathway for creating a more equitable, region-sensitive and effective GB certification framework. Further research is essential to ensure that certification standards align with user experiences and promote long-term wellbeing.

This study identifies key limitations within the LEED rating system and offers practical suggestions for its improvement. However, there are several unexplored avenues for future research. First, future research could expand the geographical scope by examining LEED-certified buildings in various international contexts. A comparative approach would yield deeper insights into how regional differences affect credit achievement and sustainability outcomes, helping to identify global patterns and establish more universally relevant benchmarks. Second, assessing the long-term effectiveness of LEED-certified buildings is crucial to determine whether high initial ratings result in lasting environmental and social benefits. Conducting post-occupancy evaluations would provide critical data on the real-world performance of GBs, highlighting areas where the LEED rating system may need further refinement. Third, the configurational analysis in this study aimed to identify various pathways within LEED categories that lead to achieving a high GB rating. Future research could extend this approach by conducting configurational analysis at the credit level, providing a more detailed examination of how specific LEED credits contribute to overall performance. Analysing LEED credits could help uncover specific pathways to achieving a high GB rating that may remain obscured at the category level.

Fourth, this research discussed the impact of credit overlaps qualitatively. Thus, future research should develop a quantitative framework to assess such impacts. In fact, a quantitative approach enables a more precise evaluation of how such overlaps influence a high LEED score, potentially identifying redundancies or synergies. In parallel, incorporating external contextual factors – such as regional regulatory policies, market dynamics and climatic conditions – into configurational models would enhance the explanatory power and policy relevance of the findings. Finally, while this research recommended three targeted reforms to strengthen the evaluation rigour of the LEED rating system, it did not explore the connections between these reforms and LEED improvement. Theory of change models can help examine these connections (Mayne, 2015). This highlights the need for future research to use theory of change to assess how the causal links between these reforms and the support from developers and occupants can lead to better outcomes for GBs.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data that support the findings of this study are available from the corresponding author, S.A. Z, upon reasonable request.

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