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Are LEED-certified healthcare buildings in the USA truly impacting sustainability?

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Abstract

Healthcare buildings are energy and water intensive, which remarkably impacts their sustainability. They also share a larger portion of hazardous and non-hazardous wastes. Leadership in Energy and Environmental Design (LEED) has been rating healthcare buildings under a separate category of Building Design and Construction (BD + C): Healthcare to acknowledge their role and importance. This research investigates the credit points achieved by these buildings using all versions and rating systems of LEED BD + C: Healthcare. The results report a very small number of Platinum-certified buildings as compared to other certification levels. Further, Technique for Order of Preference by Similarity to Ideal Solution is applied on credit points and certification levels according to their rating system, climate and location to reveal that buildings require a lot more effort to raise their certification level from Gold to Platinum as compared to the effort required between Gold, Silver and Certified. Based on this, a new certification level is proposed. Furthermore, buildings located in dry weather and South region of the USA have been shown to achieve better credit points. The findings can help designers in scoring better LEED points, which could help promote the culture of rating systems.

Keywords

LEED, Healthcare, Credit points, Climate, Location, Sustainability

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Introduction

One of the basic human needs is buildings. More people require more buildings for various purposes of their daily life from house to work and to health amenities.[1] A large expanse of resources is involved in building construction including materials, energy and personnel. Despite their established benefits and luxury to humans, buildings come with some undesirable outcomes such as carbon footprint, resource depletion and other environmental issues. On top of construction processes, the operation and maintenance phases of buildings have a massive impact on sustainability.[2] It is reported that buildings are responsible for one-third of global greenhouse gas (GHG) emissions by consuming 40% of total energy and resources, 25% of water[3] and 70% of timber per year.[4]

The eventual solution for this problem is sustainability; inescapable on earth from infrastructure to life style of humanity. Mahdavinejad et al.[5] argue that the built environment can only be sustainable if its every aspect from planning to construction, operation

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and disposal are considered equally. Serious effort should be put towards making the build more environmentally, socially and economically sustainable. Thus, the aim of sustainable construction is to minimize all negative impacts of a building[6] without compromising health and comfort of occupants. Such sustainable built environment is usually achieved through green buildings[7] which use less water, less energy and recycled materials and rely upon efficient technology to minimize unwanted environmental impacts.[8]

Environmental footprint of buildings depends on their use too; for instance, commercial and industrial buildings have larger impacts than their residential counterparts. Healthcare buildings are ranked second as per their environmental shortcomings.[9] In 2013, healthcare sector in the USA was liable for 8% of total air pollution involving 12% acid rain, 10% GHG emissions, 10% smog formation, 9% criteria air pollutants, 1% ozone depletion and 1–2% carcinogenic and non-carcinogenic air toxics.[10] According to Commercial Buildings Energy Consumption Survey of US, healthcare buildings especially large hospitals have higher energy use as compared to other commercial buildings.[11,12] Moreover, hospitals are the second largest waste producers which also contains highly toxic materials.[13] Categorically, it strengthens the need of sustainable healthcare buildings not just for reduced environmental impacts but also for improved health services.

To ensure delivery of such sustainable built environment, development and standardization of sustainability criteria are essential. In this regard, numerous attempts have been made to acquire novel benchmarks for establishing a peer group of high-performance and sustainable built environment. A popular category of such benchmarking efforts is green building rating systems.[14] Among these, Leadership in Energy and Environmental Design (LEED), developed by the United States Green Building Council (US GBC), is one of the principal approaches. LEED evaluates the performance of green buildings and assigns a credit-based rating. Each credit assesses an element of a building's performance and marks qualified credit points. The sum of all the scored credit points determines the certification level varying from Certified (40–49), Silver (50–59), Gold (60–79) to Platinum (80–110).[15]

LEED has a variety of credit points for rating different categories of buildings like new construction (NC), renovations, office, residential, healthcare and institutional buildings. LEED for healthcare is a specific rating system for inpatient, outpatient and licensed care facilities. It has same basic standards like other rating systems but also considers healthcare-sensitive strategies such as connection to natural world for patients and reduction of water use in cooling equipment to evaluate the building.[16]

Cheng and Ma[17] stated that for construction stakeholders and managers, it is highly significant to select target LEED credits because of time and cost constraints of projects. Few researchers have endeavoured to investigate factors that control selection process of LEED credits. For example, Madanayake and Ruwanpura[18] explored a strategy to select LEED credits depending upon environmental impacts, cost and productivity of projects. Ma and Cheng[19] considered how target LEED credits are influenced by the associated LEED credits. The relation between cost of project and achievement of credits in different green building rating systems has been explored by Juan et al.[20] followed by proposal of a strategy for choosing any of the green building technologies. Castro-Lacouture et al.[21] developed a material selection strategy for LEED projects based on potential factors of design and budget to maximize credit points achieved with minimum cost in Material and Resource category of LEED. Zhao and Lam[22] investigated the effect of city-level factors on LEED building market in the American east coast cities. On top of these aspects, climatic factors, which are very important for sustainable built environment, have also been studied and correlated to LEED credits and criteria. Research shows that target LEED credits are greatly influenced by climate factors and that is why LEED managers prefer different target LEED credits for different locations and projects. Studies in this regard have focused sunshine and other climatic factors. In a recent study by Jun and Cheng,[19] a model has been developed to predict the target LEED credit based on climate factors and projects data. Indoor environmental quality (IAQ) has been observed as the most prioritized category of LEED in case of healthcare buildings by user perspective.[23] Lee[24] also states that a positive correlation exists between IAQ and thermal comfort of healthcare buildings and higher certification level of LEED. Some researchers have gone further to investigate the role of LEED-certified green buildings in reducing environmental issues. For example, the heat island effect of built environment has been studied to establish that the increased urban temperature could affect the energy consumption of buildings.[25] Indeed, researchers have also correlated the properties of building materials with urban temperatures and how they act in reducing heat island effects.[26] However, Donghwan et al.[27] claimed that an area, where a good number of LEED-certified buildings exist, has no influence on local climate in terms of reduced temperature.

Such a detailed knowledgebase around green and sustainable built environment facilitates the decision-making process.[28] However, it is not the case when designing, procuring, constructing, operating and maintaining the healthcare facilities due to a lack of dedicated research. It is pertinent to note that such a synthesis could help put into perspective the state of the art and variety of practice in LEED-certified healthcare buildings to assess the current norms and act as decision support for future endeavours.

Aim and objectives of research

The aim of this research is to find out how the credit points vary over different certification levels of LEED-certified buildings and which categories are preferred by building owners to achieve desired LEED certification. This is achieved through the following objectives:

- To assess areas where selected certified buildings are scoring comfortably and where they are struggling.
- To examine the scoring difference, impact of a particular certification level on sustainability and amount of effort required to upgrade the building from a lower to higher level of certification.

The scope of this study is limited to LEED-certified healthcare buildings in the USA because of their economic, social and environmental status quo. To achieve the set objectives, detailed data of 412 healthcare buildings spread across the USA were obtained. The US-based projects were selected due to LEED's conformity with American codes, rules and regulation. Gurgun et al.[6] remarked that for countries other than the USA, local conditions are not abundantly reflected, making it difficult to achieve particular credit points. This research could help property owners, real estate developers and designers in conveniently achieving LEED credit points based on the experience of previous projects. On the other hand, the LEED authorities may also observe the common scoring patterns to either revise or improve the rating system in the light of such practices.

Overview of LEED

A technical instrument developed to evaluate the environmental performance of buildings is known as a rating system or green building rating system. The interest in sustainability has explicitly increased worldwide during the last decade due to severe weather events. The role of buildings is very crucial in this case especially for the reduction of GHG and consumption of resources. Consequently, a number of green building rating schemes have been developed globally, and increase in number of green buildings is expected to rise remarkably, especially in developing countries, imparting an individual attention to energy conservation.[29] LEED is the most popular and preferred rating system in the world.[2,30] US GBC pilot tested the LEED certification system in 1998 with an aim to efficiently use resources for reduction of GHG emissions and harmful aspects of materials.[28] LEED has been widely used inside and outside the US. For instance, according to the US GBC annual press release in 2018 of top 10 countries and regions for LEED, USA has 33,632 (441.60 million gross m^2), China 1211 (47.16 million gross m^2), Canada 2970 (40.77 million gross m^2), India 752 (20.28 million gross m^2), Brazil 461 (14.83 million gross m^2) and Germany has 276 (7.00 million gross m^2) LEED-certified projects as of 31 December 2017.[31]

One of the major reasons for LEED's global popularity is its perceived positive impact on sustainability. It has been reported that 87.5% of construction management personnel closely involved in the LEED certification process did not find any instance of negative unintended environmental consequences due to their certified buildings.[32] LEED has not been restricted to positively impact the sustainability of certified building only, but it also has a positive impact on the surrounding of that building. For instance, Shin et al.[33] found that constructing an LEED building in a 30 m boundary could possibly lower the temperature of the surrounding environment by 0.35°C. Also, having a higher certification level, such as Gold or Platinum, increased the lowering effect by 0.48°C. However, it is also reported that LEED certification levels and the mass effect of LEED buildings do not have a significant influence on regional climate.[27] So, even though LEED has gained a substantial amount of interest and scepticism, its impact on sustainability has yet to be established.[33] This is a major objective of the current study in the context of healthcare buildings.

LEED offers multiple rating systems which includes BD + C: Building Design and Construction, ID + C: Interior Design and Construction, O + M: Building Operations and Maintenance, ND: Neighbourhood Development, Homes, Cities and Communities.[34] From conceptual planning to construction, these projects can be at any stage of the development process. Planned and built projects may also be included, for example, Homes apply to single families, low-rise multi-family (one to three storeys), or mid-rise multi-family (four to six storeys) homes.[35] Out of all these rating systems, only BD + C applies to healthcare facilities.

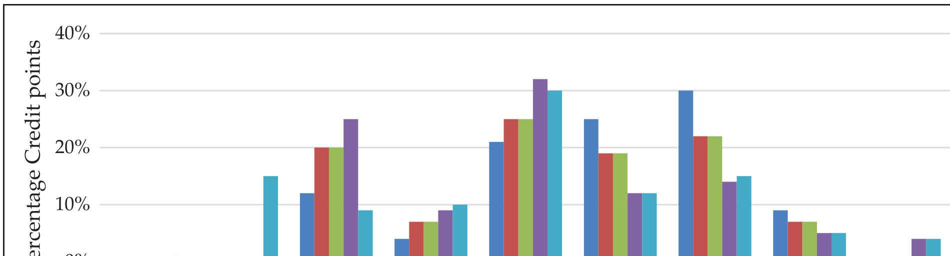
Further, depending on the type of project, each rating system has some variation in credits, but the maximum credit in latest versions is 110. As per LEED v4, these points are divided into nine categories within the scorecard. The categories are integrative process (IP), location and transportation (LT), sustainable sites (SS), energy and atmosphere (EA), water efficiency (WE), material and resources (MR), indoor environmental quality (EQ), innovation (IN) and regional priority (RP). The categories of IP and LT did not exist in prior versions. Similarly, RP was introduced in LEED v3 and did not exist before.

Most LEED credits are performance-based, not prescriptive. For instance, the system demands the vehicles to simply meet the minimum performance criteria to award points, with no mention of their make and model. Precisely, the intent of sub-credit SS-4.3 is simply to 'reduce pollution and land development impacts from automobile use'; the choice of how is used, is up to the user. LEED also provides guidelines to achieve the particular credits, but if there is another alternative unlisted method, the user has the flexibility to pursue an alternative compliance path to demonstrate the achievement of the intent of credit. This encourages the user to innovate, which is proposed and promulgated.[36]

LEED has evolved since its inception in 1998. During this time, many of its versions were rolled in and out starting from pilot version to v2.0, v2.1, v2.2, v3 (v2009) and v4. LEED v2.2 and v3 are two major versions of LEED and more than 5000 buildings are certified under v2.2 since its inception in 2005. Later, LEED v4 was launched in 2013. However, its predecessor persisted until October 2016.

LEED BD + C: Healthcare is a specific rating system for hospitals and other healthcare facilities which function on a 24-h schedule. The reduction of energy and water use and improvement in environmental quality give hospitals an opportunity to be vigorous to provide a healthy built environment. LEED can help these facilities to be more efficient and achieve satisfaction of patients and staff by playing its role in the overall sustainability.[16] LEED is not directly targeting the overall sustainability of building but is contributing toward the sustainability by evaluating the use of energy and water, environmental impact and indoor air quality of buildings.[37] LEED is also focusing on the use of new and sustainable material, SS and sustainable use of transport. These factors indirectly improve the sustainability of any building.[38] In order to analyse the evolution in the vision and focus of LEED for healthcare buildings over the years, LEED versions are compared in BD + C for all of its rating systems including Healthcare, Commercial Interior (CI), Core and Shell (C&S) and NC according to their credit point allocation for different components of the green infrastructure. The evolution of LEED credit points over different versions and rating systems are shown in Figures 1 to 4 for NC, CI s, C&S and Healthcare, respectively.

For example, in BD + C: NC, except IP and LT which were introduced in v4, other categories show an evolution of credit points in different versions, as shown in Figure 1. The percentage credit points of each category in v2.1 and v2.2 are equal. SS was given 12% weightage in v2.0 which kept on increasing up to 25% in v3 but in v4 it has been reduced to 9% only. Due to the introduction of two new categories, IP and LT, the maximum reduction is witnessed in SS category from 25% in v3 to 9% in v4. A close look at the sub-credits in each category reveals that till v3, transportation was also catered under SS but in v4, it has been made a separate entity as Location and Transportation (LT) which is given more credit than SS. This shows that location of a building has a huge impact on its



	IP	LT	SS	WE	EA	MR	EQ	IN	RP
v2.0	0%	0%	12%	4%	21%	25%	30%	9%	0%
v2.1	0%	0%	20%	7%	25%	19%	22%	7%	0%
v2.2	0%	0%	20%	7%	25%	19%	22%	7%	0%
v3	0%	0%	25%	9%	32%	12%	14%	5%	4%
v4	1%	15%	9%	10%	30%	12%	15%	5%	4%

Figure 1. Comparison of LEED credit points of all versions for New Construction.
IP: integrative process; LT: location and transportation; SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: material and resources; EQ: environmental quality; IN: innovation; RP: regional priority.

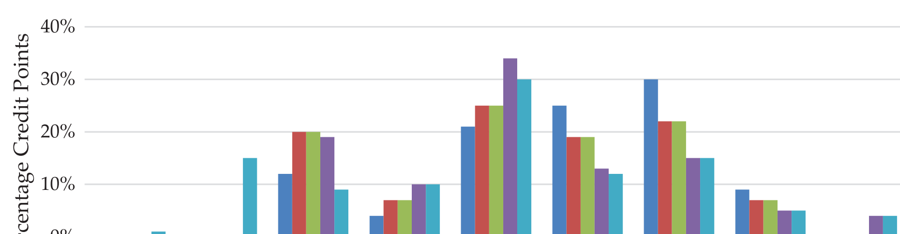
sustainability which is operationalized in the form of transportation.

Further, the credits in the WE category have been consistently increasing from 4% in v2.0 to 10% in v4. This is reasonable because of water scarcity at the global level.[14]

Similarly, credits of EA increased from v2.0 (21%) to v3 (34%), but slightly decreased in v4 (30%). Conversely, credits given to MR have been experiencing a steady fall across all LEED versions from 25% in v2.0 to 12% in v4, but on the whole, it has very positive and practical changes in the latest version, for instance, the life cycle approach for building materials and waste reduction on site.[39] In the same fashion, the percentage of EQ was reduced to half from v2.0 (30%) to v4 (15%). Also, a steady decreasing trend is observed in the IN category from 9% in v2.0 to 5% in v4.

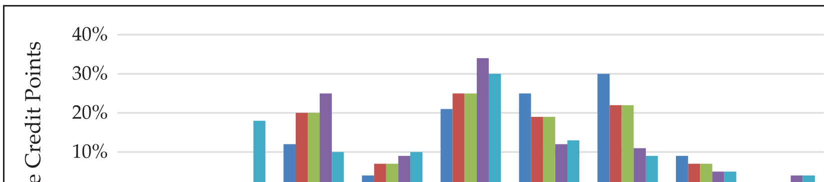
In BD + C: CIs, the trend in percentage credit points in each category is just like that of NC, with some minor variations, as shown in Figure 2. The rating system in LEED v3 has a few notable variations, such as SS has 19% credit points compared to 25% in BD + C: NC. Similarly, minor changes have been observed in all other categories.

Further, as shown in Figure 3, BD + C: C&S gives more credit to SS (10%) and LT (18%) but less credit to EQ (9%) in LEED v4 as compared to that of NC and CIs. The C&S is the construction of the base building, where a range of other construction and fit out works are left to be completed before the building is occupied. Several healthcare buildings are certified



	IP	LT	SS	WE	EA	MR	EQ	IN	RP
v2.0	0%	0%	12%	4%	21%	25%	30%	9%	0%
v2.1	0%	0%	20%	7%	25%	19%	22%	7%	0%
v2.2	0%	0%	20%	7%	25%	19%	22%	7%	0%
v3	0%	0%	19%	10%	34%	13%	15%	5%	4%
v4	1%	15%	9%	10%	30%	12%	15%	5%	4%

Figure 2. Comparison of LEED credit points of all versions for Commercial Interiors.
IP: integrative process; LT: location and transportation; SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: material and resources; EQ: environmental quality; IN: innovation; RP: regional priority.



	IP	LT	SS	WE	EA	MR	EQ	IN	RP
v2.0	0%	0%	12%	4%	21%	25%	30%	9%	0%
v2.1	0%	0%	20%	7%	25%	19%	22%	7%	0%
v2.2	0%	0%	20%	7%	25%	19%	22%	7%	0%
v3	0%	0%	25%	9%	34%	12%	11%	5%	4%
v4	1%	18%	10%	10%	30%	13%	9%	5%	4%

Figure 3. Comparison of LEED credit points of all versions for Core & Shell.
IP: integrative process; LT: location and transportation; SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: material and resources; EQ: environmental quality; IN: innovation; RP: regional priority.

under this category. This follows the same trend in EA (30%) and WE (10%), but credits in MR (13%) have marginally increased in the latest version (v4). As healthcare buildings are health sensitive and is supposed that these buildings must have a better environmental quality to provide patients with a better space for their comfort, the overall credits of EQ have been reduced from 30% to just 9%. However, LEED has not reduced the sub-credits and mandatory requirements in EQ, which means the overall environmental quality of healthcare building is not compromised. Subsequently, the individual weightings for sub-categories have been altered. Some of the sub-categories such as Environmental Tobacco Smoke Control, Minimum Indoor Air Quality, Green Cleaning Policy, Outside Air Introduction and Exhaust Systems, Asbestos Removal or Encapsulation and polychlorinated biphenyl removal have now been made mandatory. Therefore, the effect of reduction in total credit points for this category on the environmental performance of these buildings is nil. The reason behind this reduction in credits of different categories like MR, EQ, SS and IN is to introduce new categories that may have better impact on sustainability by improving the overall performance of healthcare buildings. This inclusion is performed keeping the total score intact, following the triple bottom line approach of sustainability. Therefore, when such new categories are introduced, credit score of existing categories is adjusted in such a way that seemingly significant categories outweigh those which have slightly lesser impact on sustainability.

BD + C: Healthcare was introduced in v3 only. Therefore, it has two versions: v3 and v4. As shown in Figure 4, points have been increased in WE (10%) and MR (17%) but decreased in SS (8%), EA (32%) and EQ (15%). Whereas IN (5%) and RP (4%) remain constant.

Limitations of LEED

Suzer[40] concluded that LEED v3 offered substantial improvements as compared to previous versions like v2.2, where every credit had a weightage of 1 and the sum was 69. The author argued that each point has different impact on reducing the environmental effects; hence, the credit weighting should not be equal for each point. LEED v3 has also removed the issues related to local factors by introducing innovations. According to Wu et al.,[41] RP offers bonus points for particular regional characteristics, such as energy and water conservation. Also, there are no credits related to human health in LEED in order to find out how a building is affecting the inhabitants socially.[42]

There are less buildings certified under v4 as compared to those of v3 which is mainly due to novelty of the latest version and resistance to change on the part of construction and building industry. Despite a wide application of LEED certification system, some problems have been found in it. Karakhan[14] stated that LEED's claim to sustainability is not truly substantiated due to some missing social aspects. Asdrubali et al.[39] argued that town planning may interfere and affect the site sustainability which has been given almost 25% credit in LEED. Wu and Low[43] found that LEED neither includes any credit for project management process nor provides a framework for the development process of green buildings as compared to other rating systems. Zimmerman and Kibert[44] described LEED as a 'one-size-fits-all' which means buildings of every size from small house or office to skyscraper situated in any bioregion can be evaluated. Despite such limitations, LEED is still a valid rating system, constantly attempting to ensure building's sustainability. In the spirit of meeting its objectives, US GBC strives to improve LEED by incorporating new problems and their solutions.[40]

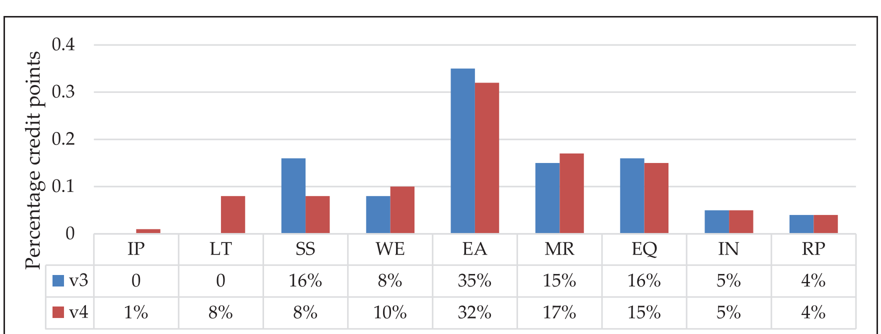


Figure 4. Comparison of LEED credit points of all versions for Healthcare.
IP: integrative process; LT: location and transportation; SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: material and resources; EQ: environmental quality; IN: innovation; RP: regional priority.

Methodology

Based on the objective of this research, which is to analyse the strengths and weaknesses of LEED-certified healthcare buildings in the USA, the study was performed in three distinct phases of data collection, data processing and analysis and results. The adopted research framework is given in Figure 5.

Data collection

The data for this research, in the form of credit points achieved by healthcare buildings using different rating systems and versions of LEED, were obtained through the official online records of US GBC.[45] The targeted data for this research were healthcare buildings certified in all versions in LEED BD + C category including NC, C&S, CIs and Healthcare. While mining for only healthcare buildings in US GBC database, multiple search filters were applied which included Certified (yes), Country (US), Name contains (hospital, medical, health, centre, clinic) and Version (all). As a result, a total of 412 buildings were selected for this research. They also consist of medical universities and health clinics certified by LEED. Of the 412 healthcare buildings, their distribution under different rating systems and versions is shown in Figure 6. Most of these buildings (299) that were certified under NC system show that the selected healthcare buildings were either

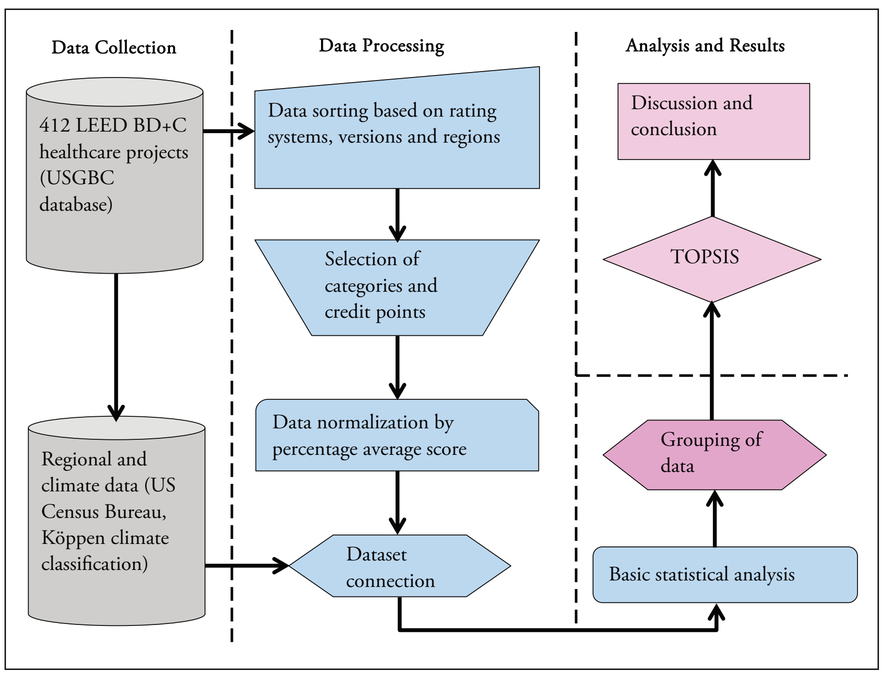


Figure 5. Framework of research methodology.
LEED: Leadership in Energy and Environmental Design; TOPSIS: Technique for Order of Preference by Similarity to Ideal Solution; US GBC: United States Green Building Council; BD+C: Building Design and Construction.

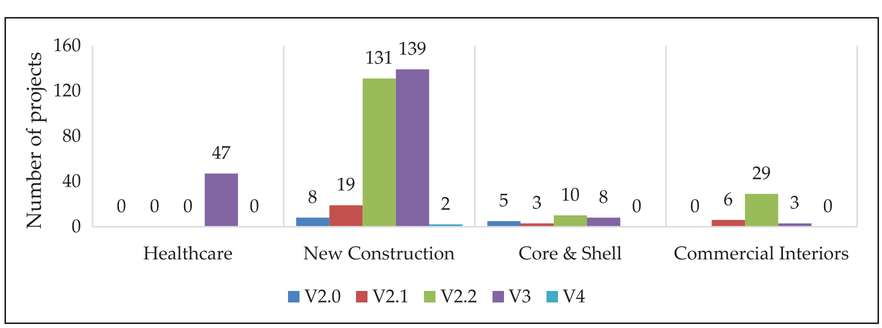


Figure 6. Number of selected projects in different LEED versions.

primarily designed and constructed in keeping with the sustainability considerations or have undergone major renovations to enhance their sustainability. Also, most of buildings (197) were certified under v3 which remained implemented between years 2009 and 2016.

Basic statistics

As obvious from Figure 6, the number of buildings is not enough for each version to produce reliable statistical results. Therefore, mean, mode, median and standard deviation of credits obtained against each category were calculated for only those versions that contain at least eight projects, as lesser number of buildings would not yield better statistical results. Thus, 19 buildings belonging to 12 out of 20 versions have not been included in the analysis, leaving behind 393 buildings. Percentage of average score in each category was also calculated to determine the critical category in each rating system. Data were sorted for two more categories which are certification level (Certified Silver, Gold and Platinum) and location of buildings in different states of the USA. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) was used to find out the impact of a particular certification level on the sustainability of a building and the level of effort required to upgrade from one certification level to the next. Lastly, correlation analysis was performed to find out the relation between the annual mean temperature of different states and their average LEED score. In this study, location refers to different states of the USA to find the geographical distribution of LEED-certified healthcare buildings across the country as shown in Figure 7. California has the most LEED-certified healthcare buildings as given by a darker shade. On the other hand, Virginia, Missouri and Louisiana have the least number of these certified buildings. Also, some states such as Nevada, Colorado, etc. do not have any LEED-certified healthcare building as extracted through search criteria used in this study.

TOPSIS analysis

TOPSIS is a multi-criteria decision-making technique which is used to find the geometrical distance of selected alternatives from ideal positive and ideal negative solution.[46–48] If the distance of the alternative from a positive ideal solution is minimum and from a negative ideal solution is maximum, this shows that the alternative is ideal. TOPSIS is one of the methods of multi-criteria decision-making that can be used to attain the most optimized choice out of available choices. Papapostolou et al.[49] used TOPSIS method to evaluate alternative policy scenarios to achieve the EU's 2030 renewable energy target. Similarly, Vidal and Sánchez-Pantoja[50] argued that the multi-criteria decision-making based on the life cycle assessment and TOPSIS can be used to obtain single scores to valuate award criteria for the green public procurement. TOPSIS is also a handy method for optimization of various manufacturing processes that have been optimized by this method and can also contribute to decision-making for the sustainable development.[46,51] Basically, all alternatives in hand are ranked based on their distance from the ideal solution. The positive ideal solution gives maximum benefits with a minimum cost, and the negative ideal solution gives minimum benefits

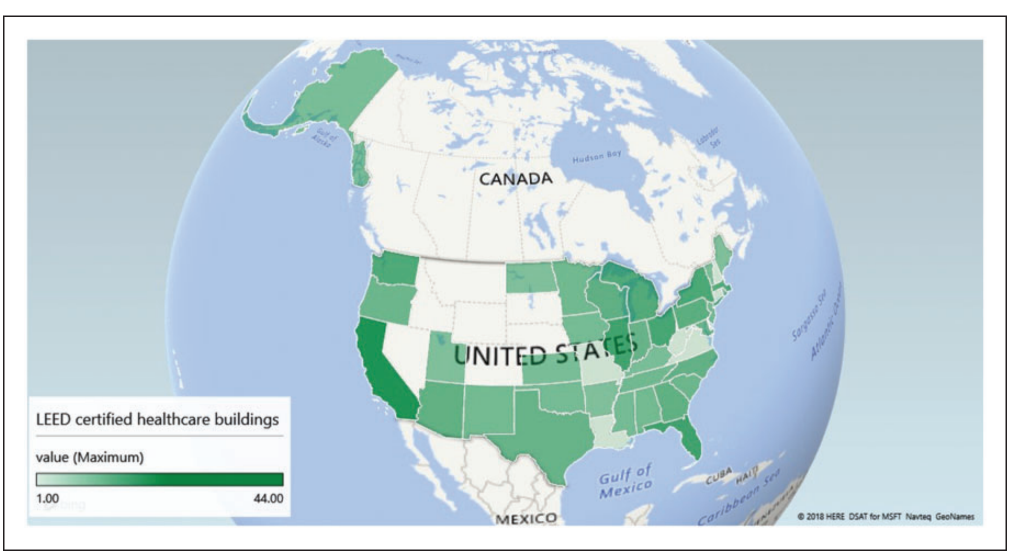


Figure 7. Geographical distribution of selected projects.

with a maximum cost. Hence, the selected alternative is always the one which is the closest to a positive ideal solution. In this study, there are nine scoring categories which directly contribute to the four certification levels from Certified to Platinum. That is why TOPSIS is used to find out which LEED categories are preferred by the building stakeholders to achieve certification among four alternatives and what is their order of preference including the distance between certification levels. TOPSIS can also demonstrate how much effort is needed to promote from a lower to a higher certification level and which certification level offers more sustainability.

First, a matrix of alternatives and criteria is constructed as shown in Figure 8.

The alternatives considered in this case are the certification levels and criteria are categories which include the standard LEED categories of SS, WE, EA, MR and EQ. The remaining categories were not included since two of them, IP and LT, are introduced in v4 only. Also, RP and IN were purposefully not included in this analysis because all rating systems and certification levels have higher and comparably similar score in these categories.

The standard TOPSIS methodology consists of five steps. In the first step, each alternative a_i; $i = 1, 2, \ldots, m$ was described by attribute values f_j; $j = 1, 2, \ldots n$ and marked as x_{ij}; $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. Criteria f_j may be of profit (benefit) or expenditure (cost) type.[52] Profit type criterion means that a greater value of attribute is preferred to a lesser attribute value (herein represented by 'max'), while the cost type criterion means that a lesser attribute value is preferred to a greater value of attribute (herein represented by 'min').

All categories were considered to be 'max' because the goal is to achieve the highest level of certification.

The second step required a calculation of the normalized matrix using the vector normalization, whereas

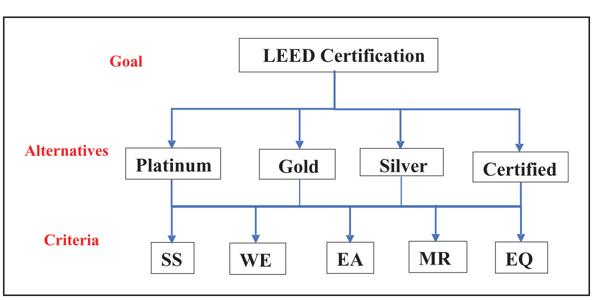


Figure 8. TOPSIS decision matrix.
LEED: Leadership in Energy and Environmental Design; SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: material and resources.

the matrix elements for the max type criteria are given as per equation (1).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (j = 1, \; \ldots . \; n) \tag{1}$$

This results into a normalized decision-making matrix. Further, the third step required taking a product of normalized matrix elements with normalized weight coefficients w_j; $j = 1, 2, \ldots, n$ such that the sum of weights equals 1, which in this study is equal to the weighting given to each category by LEED. For instance, in the NC, the total points of EA are 35 and the weight given to this category is 0.35. Therefore, a modified decision-making matrix whose elements can be represented by $v_{ij} = w_j \times r_{ij}$. The third step determines the ideal and anti-ideal points in an n-dimensional criteria space, such that the ideal points are maximum in each column and anti-ideal are minimum.[52]

The fourth step required a calculation of the Euclidean distance S_i^+ of each alternative a_i for an ideal solution as given in equation (2), which represents the Euclidean distance of the i^n alternative from an ideal point. Further, S_i^- for an anti-ideal solution, this was calculated using equation (3), which represents the Euclidean distance of the i^n alternative from an anti-ideal point.

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, \; i = 1 \ldots m \tag{2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \; i = 1 \ldots m \tag{3}$$

The fifth step was to calculate the relative similarity of alternatives from ideal and anti-ideal points which was done using equation (4).

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}; 0 \leq C_i \leq 1; i = 1 \tag{4}$$

If $C_i = 1$, then $a_i = A^+$ and if $C_i = 0$, then $a_i = A^-$. Therefore, the conclusion is that a_i is closer to A^+ if the C_i is closer to 1, meaning that the bigger the C_i is, the better the alternative would be. At the end of this process, the results are discussed and conclusions are drawn. Using these conclusions as well as strengths and limitations of this research, implication for future studies and industrial application are discussed.

Results and discussion

Using the structured methodology, 412 certified buildings situated in the USA were initially shortlisted. After eliminating the 19 buildings which were certified under versions that contained less than 8 buildings, 393 certified healthcare buildings were selected for further analysis.

Analysis of rating system vis-à-vis categories

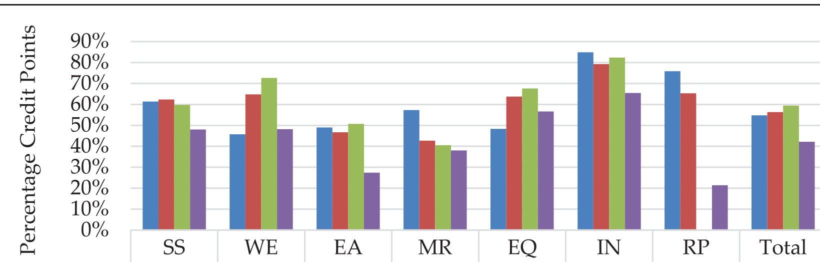
The central tendency of data was assessed. As a result, the average of percentage score achieved against each category by buildings certified under different rating systems are compared in Figure 9. The figure shows that, on average, all buildings have more than 60% score in IN, but are struggling in EA and MR, the two major categories which are highly important in terms of sustainability and greening of buildings. An average score of all rating systems in EA and MR is below 60%, meaning that either achieving credits in these categories are difficult or costly as compared to other categories, for instance, RP and IN.[15,28,53] This is because, to achieve a better score in MR, expensive materials like admixtures and plasticizers in concrete, glazing glass and leakage-free frames in windows and many other costly materials are required. Similarly in EA, expensive equipment like energy efficient lighting, solar panels for energy production, thermal insulating materials in roof and walls, etc. are required to score better.[54]

A detailed observation of Figure 9 reveals that Healthcare and C&S projects are struggling in WE and EQ, as these projects scored less than 60% in these categories. Healthcare projects are health sensitive that is why these projects should have large value of EQ for better efficiency and quick patient recovery. Similarly, to have a higher positive impact on sustainability, Healthcare projects must perform better in WE. However, in this case, these projects are also struggling in WE (46%) along with EA (49%). Looking at the overall performance of all projects as per total score in Figure 9, these projects on average have less than 60% total credit points.

Specifically, C&S projects performed unsatisfactorily as these projects have only 42% average credits points. Quite the opposite, CIs performed relatively better by scoring nearly 60% credit points, whereas remaining two rating systems, Healthcare (55%) and NC (56%), also performed marginally by scoring in between the other two systems. LEED is an established green building rating system and its certified projects should perform better at least in the environment-related categories such as WE, EA, EQ and MR. However, as shown in Figure 9, all LEED-certified healthcare projects performed disappointingly in these indicators, leaving ordinary impact on sustainability. These findings point towards a need that US GBC should revise the system in such a way that compels the stakeholders to focus on these categories to produce a remarkable impact on the overall sustainability. Similar conclusion has also been reached by previous studies.[28] The limited performance of EA can be attributed to various causes, such as energy modelling,[55] latent need,[56] changes during execution,[57] etc.

Analysis of certification level

Moving further, when the data were analysed against the level of certification, very few projects with higher certification level were found. Typically, buildings have Certified (75) and Silver (165) levels. Also, a sizable population (56) of Gold certified was found, but



	SS	WE	EA	MR	EQ	IN	RP	Total
Healthcare	61%	46%	49%	57%	48%	85%	76%	55%
New Construction	62%	65%	47%	43%	64%	79%	65%	56%
Commercial Interiors	60%	73%	51%	41%	68%	82%	0%	59%
Core & Shell	48%	48%	27%	38%	57%	65%	21%	42%

Figure 9. Comparison of percentage credit points.
SS: sustainable sites; WE: water efficiency; EA: energy and atmosphere; MR: material and resources; EQ: environmental quality; IN: innovation; RP: regional priority.

Platinum-certified (17) buildings were very few. For instance, there is only one platinum-certified hospital in BD + C: Healthcare out of 47 total entries. There is no Platinum-certified project of C&S among the selected projects.

Analysis of certified buildings vis-à-vis regions

The data were also analysed to see the trends of average score vis-à-vis their state-wise location. An inclusion criterion of minimum 10 projects was set. Thus, states with 10 or more projects were considered for this analysis to representatively and substantially comment on the trends. As a result, 15 states were included in this analysis. Figure 10 represents the trend of percentage total score of healthcare buildings in selected states. To check for variance, a single sample t-test was performed. The results reveal that the t-value is 0, the value of p is 0.5 and the result is not significant at $p < 0.05$. Thus, there is no significant difference in the average total score in all states, such that an average LEED score of 52% was achieved by the selected 397 healthcare buildings. Upon further observation, California (44) has most projects followed by Florida (28), but it has no such effect on the average of the percentage total score. Considering the inclusion criterion, the least number of certified buildings were located in Arizona (12) and North Carolina (11). Further, no state has more than 60% average total score which means that most buildings in all states have Certified and Silver certification levels, and buildings with Gold and Platinum certification levels are so few that it has no effect on the mean value.

TOPSIS analysis

Further, the credit points achieved by buildings in each rating system were analysed through TOPSIS to find out their relative proximity in five categories as explained in the previous section. The results are presented in Figure 11, showing that the higher certification level tends to have a higher score in all categories which is very intuitive to understand, since total credit points required to reach a certain certification level increases from Certified to Platinum. A building needs to score 80 or above out of 110 points to achieve the Platinum certification in the latest versions (v3, v4). Closely examining the graphs shows that the difference in average score obtained by buildings is not uniform in any rating system. For example, in Healthcare, the gap between Certified–Silver (32%), Silver–Gold (13%) and Gold–Platinum (55%) is not equal, whereas the LEED points for Silver to Platinum increase with a constant value.

Technically, each certification level has a direct impact on the building performance and an indirect impact on the overall sustainability.[58] From Figure 11, the impact on sustainability by Silver and Gold-certified projects is much less as compared to Platinum. Figure 9, for the reason of this phenomenon, shows that these projects have achieved lesser credits in WE, MR and EA categories which are the absolute indicators of sustainability. In the C&S, there is not a single Platinum project and a few projects certified in other categories; therefore, this rating system may not be compared with other three.

Figure 11 shows that, excluding C&S, on average, Silver and Gold have only 32% impact on sustainability which should be 62% according to LEED points. The results suggest that these projects have almost half the impact as compared to their originally intended and specified impact. This is because, to achieve the lower certification levels, some categories were ignored, but still the certification was achieved by performing good in categories where achieving credit points is easier such as IN, RP and SS. Therefore, there is an overall 30% gap in these planned and achieved sustainability by selected LEED-certified healthcare buildings. Only the Platinum level has a substantial impact on sustainability because to achieve it, the project needs to score

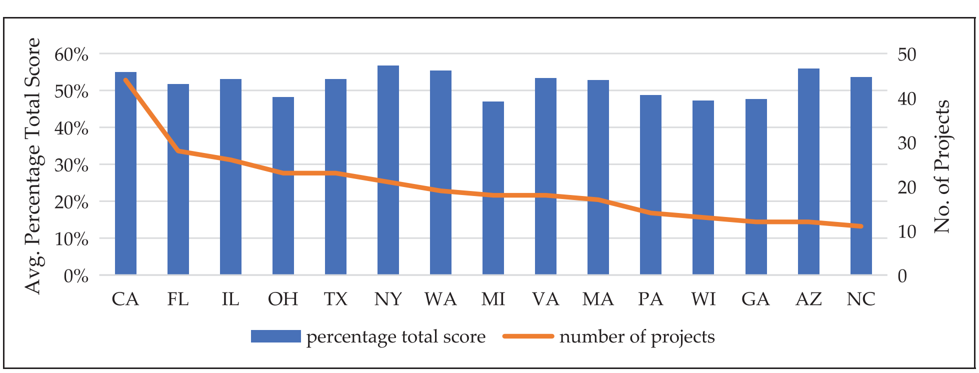


Figure 10. Location vs. average of percentage total score.

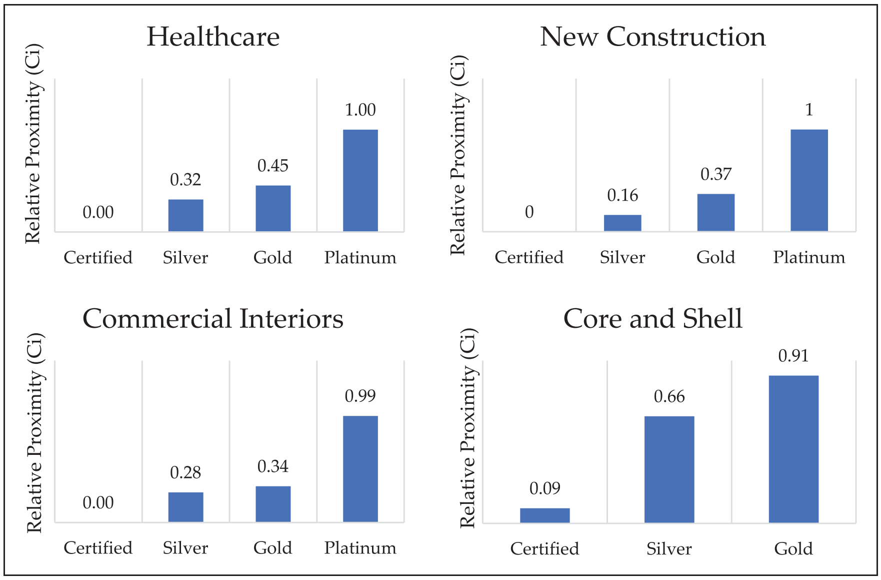


Figure 11. TOPSIS results of certification levels score.

equally high in all categories. Thus, the relative proximity is also the indicator of similarity in terms of level of effort or level of impact on sustainability among these certification levels. Although there is a lesser difference between the values of C_i, a similar level of effort is required to move from one level to the other and vice versa. A greater value of C_i represents a better performance of particular buildings and promises more impact on sustainability. From Figure 9, there are several categories that contribute in the LEED certifications but do not represent the level of effort required to move from one level to other level of certification. The level of effort is given in Figure 11 along with the impact of buildings on sustainability.

The possible reason for less gap between Silver and Gold could be due to lower credit points achieved by these levels mostly in EA and MR categories. At this stage, the level of effort required to achieve Gold instead of Silver is comparatively less than that of required to achieve Platinum instead of Gold. To target Platinum would require top notch credits in all categories, whereas targeting Gold would require marginal additional credits than achieved for Silver. Thus, every successive move from lower to higher certification level, despite having a constant difference of total credits, is not the same. Also, achieving the highest level of certification is both extremely costly as well as effortful. However, to achieve a minimum level of certification is relatively easier than mostly thought by building owners and real estate developers. This finding may act as a catalyst to promote LEED certification of healthcare facilities even at a lower level.

The analysis has also been performed on the average score obtained in different categories of provided rating

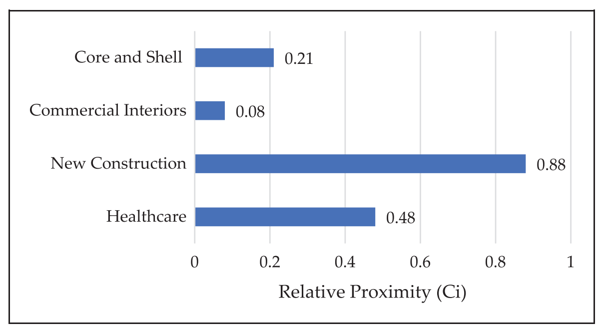


Figure 12. TOPSIS results of rating systems score.

systems, as shown in Figure 12. Credits achieved by CIs ($C_i = 0.08$) and C&S ($C_i = 0.21$) are lesser in all categories as compared to NC ($C_i = 0.88$) and Healthcare ($C_i = 0.48$). NC shows a higher rank in this analysis which points to a greater number of projects certified under this system due to a convenience of scoring higher credit points.

Afterward, climate-based TOPSIS analysis was performed. For this purpose, the data were grouped based on the Köppen climate classification using the location of selected buildings. The aim was to find out the variation in scores against various climatic characteristics. All the selected buildings were located in four climatic divisions: Tropical (A), Dry (B), Temperate (C) and Continental (D). The tropical climate is characterized by a large amount of year-round rain, whereas the dry climate experiences little rain and a huge daily temperature range. The temperate climate has warm, dry summers and cool, wet winters. The continental climate does not have a very high total precipitation, with a wider variation in seasonal temperatures.

Figure 13 shows the results of TOPSIS applied on buildings grouped as per their climate. It shows that buildings located in dry climate regions have achieved higher LEED credit points ($C_i = 0.816$) as compared to those located in other climates. The most appealing cause for this could be enough sunny days, which makes it easy to achieve more credits in energy but at the same time results in less credits in water due to reduced precipitation, diminishing the chance of storm water harvesting. Based on the available data, there was no such relation between climate and credits obtained in EA and WE. For instance, Adelante Healthcare Mesa Interiors and ASU Health Services Renovation are situated in a dry climate and both have Platinum certification; however, the former scored 8 points and the latter scored only 2 points out of 10 in WE category. Similarly, the following two healthcare buildings having the same certification level of Silver but SYHC – Euclid Family Health Centre achieved 23, whereas Mental Health Psychosocial Rehab Recover achieved 6 in EA out of 35. Hence, the climate does not seem to have any impact on achievement of EA credit points in LEED which also supports the findings of Ma and Cheng.[53]

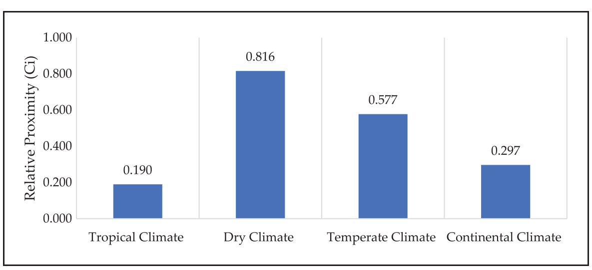


Figure 13. TOPSIS results of climate score.

Further, the tropical climate shows minimum results ($C_i = 0.190$) which means that a higher precipitation may affect the achievement of LEED points. As shown in Figure 9, almost all buildings performed well in all categories except EA and WE. Therefore, an attempt was made to evaluate the impact of climatic condition and location on LEED score especially in EA and WE. Data show that the projects located in a tropical climate performed comparatively better in WE but disappointingly lower in EA. For example, the US Naval Hospital Guam that has Silver certification and achieved 100% in WE category also performed well in other categories like in SS. This building achieved 54% (14/26), and in IN, it achieved 100% (6/6) but achieved only 8% (3/35) in EA. Moving further, the continental climate has months in which the average temperature remains below 0°C which may add up to the heating load, thus affecting the energy conservation. However, the data do not show any trend between the climate and EA points. For instance, Forest Hills Hospital Lobby achieved 30/35 points in EA, while UW Health Yahara Clinic scored only 2/35 in EA. Contrary to the continental climate, buildings located in the temperate climate ($C_i = 0.577$) have a better performance as shown in Figure 13. This climate is associated with huge temperature variations which means energy is needed both for heating and cooling purposes, and this is a probable reason of average performance. The data show that the projects located in the temperate climate on average have scored below 50% in WE and EA, whereas scored generously in EQ. For example, Jeffco Family Health Services Clinic is Gold-certified building and it has scored 5/35 points in EA, 11/15 points in EQ and 15/23 in SS.

To further strengthen this claim, a correlation analysis was performed on the average LEED score of each

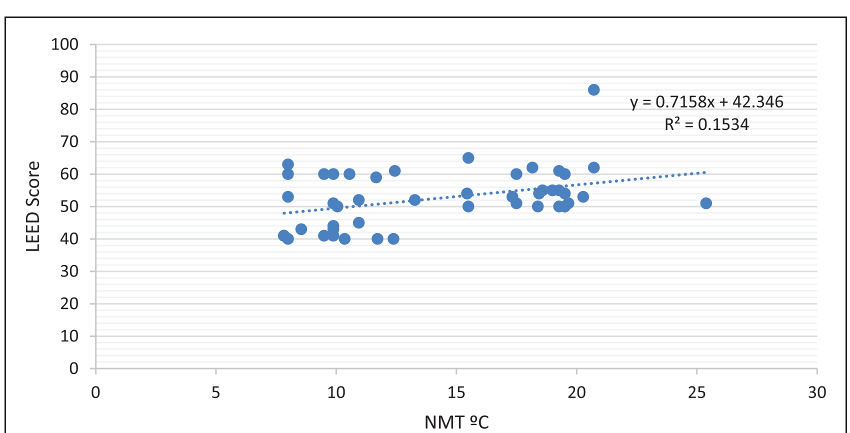


Figure 14. Correlation analysis between average LEED score and temperature.
LEED: Leadership in Energy and Environmental Design; NMT: normal mean temperature.

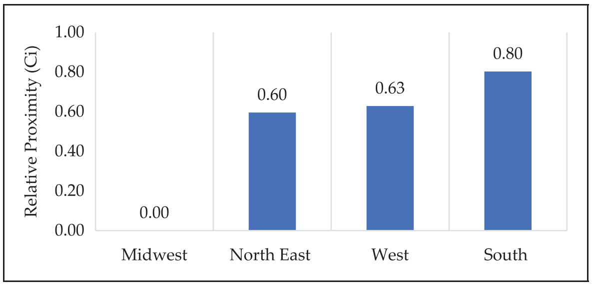


Figure 15. TOPSIS results of regional score.

state and its ambient normal mean temperature, which is the average temperature calculated for a 30-year period, currently being used here is for the period of 1981–2010. As shown in Figure 14, R^2 value is very small, which indicates that there is no relation between climatic condition and LEED score.

The data were also analysed to see how credits points change with location of buildings. The US Census Bureau defines four census regions of USA and identifies each one with a single-digit census code: Northeast (1), Midwest (2), South (3) and West (4).[59] Figure 15 shows the results of TOPSIS technique when applied on average score in different categories for LEED-certified healthcare buildings located in four regions of the USA. The lowest score is in Midwest region which may be due to its low economy and dependency on agriculture. For example, Ambulatory Care Addition and Renovation is located in Chicago and has Certified level with BD + C: Healthcare. This healthcare building has scored only 4 credit points in EA out of 39. Northeast is the most economically developed region[60] which foresees the pursuits of green technology and higher LEED score for buildings. However, in this case, the South region has achieved the maximum score which may be due to the fastest-growing areas with good economic conditions.[61] The only Platinum-certified building with BD + C: Healthcare is located in Texas (South) which is Dell Children's MCCT BT 3. Data also show that out of all selected LEED-certified projects, more buildings are located in the South region.

A further in-depth study of the regional characteristics of these areas and LEED credits may reveal deeper reasons behind such a variation.

A way forward in LEED

Every certification level has an associated impact on building's sustainability which means the higher the level of certification of a building, the more sustainable it should be. A disparity between the different certification levels represents that as LEED score gradually increases by 10 credit points from one certification level to the next till the Gold level, the impact on sustainability does not follow the same trend. Thus, justifying a very difficult jump from Gold to Platinum, the impact on the sustainability is considerably high. At the same time, the stakeholders must be incentivized for a better performance, and therefore this study proposes an additional certification level between Gold and Platinum, called Palladium. With this proposal, the scoring range must be adapted such that Gold (60–69) and Palladium (70–79) can be adjusted, following an overall linear distribution.

Due to limitations of LEED, accounting for new challenges and requirements of sustainability, LEED should undergo necessary improvements so that every certification level should target a specific impact on the overall sustainability of the building.

Conclusions and recommendation

LEED is the most popular green building rating system globally due to its vast coverage of a variety of factors and criteria. Also, it is the only rating system that deals separately with the healthcare buildings. To gauge the state of currently certified healthcare buildings located in the USA, this study performed a detailed review of secondary data obtained through US GBC database. These buildings were compared based on their achieved credit points. NCs showed the best results, since there were higher number of certified buildings under this category in the collected data. More buildings tend to have lower certification levels which is evident from very few buildings having the Platinum certification, suggesting that achieving this certification level is either difficult or costly. Additionally, the statistical analysis showed that nearly all buildings struggled to score in MR (45%) and EA (44%) categories, which is contrary to their performance in RP (54%), WE (58%), SS (58%), EQ (60%) and IN (78%). The TOPSIS analysis also reinforced this idea of buildings struggling to score higher, since Platinum has the maximum ranking in TOPSIS charts. These charts represented an uneven difference between the certification levels which indicates that the extent of struggle required for upgrading certification level varies between different levels. However, it is constant under LEED scoring system in terms of credit points. For instance, less effort is required to upgrade a building from Certified to Silver and Silver to Gold but almost double the effort is required to upgrade from Gold to Platinum. Therefore, to provide a balanced and linear destruction of credit points, a new level of certification called Palladium has been proposed in LEED.

Furthermore, buildings located in dry climate tend to have a higher level of certification and better credit points. Also, buildings located in South region of the USA could achieve more credit points as compared to other regions. Therefore, an association between climate and location of the building is suggested, with accomplishment of LEED credits, but the analysis does not support this idea. Therefore, in the design of these buildings for any certification level, the possible advantage of certain climate and location features was not contemplated. As a result, there is no harmonization of local conditions and sustainability goals. Therefore, a further study on the role of climate and location characteristics in the building's sustainability is recommended. Also, if LEED is to modify its criteria into sustainability-oriented pursuits, it would improve the design goal of owners.

The contribution of this research is the analysis of credits obtained by healthcare buildings and their variation by rating the system, location and climate of buildings. The findings can help designers in identifying categories where LEED points can be conveniently scored. The study should help the promotion of the culture of rating systems. The findings are not meant at identifying the loopholes for achieving easy points. This feature can be exploited by authorities to ensure a real impact on sustainability, no matter how many LEED points are achieved by a building.

Authors' contribution

All authors contributed equally in the preparation of this article.

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