Resources, Conservation & Recycling 145 (2019) 170–178

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

LEED certification as booster for sustainable buildings: Insights for a Brazilian context

Sasquia H. Obata[a,b,c], Feni Agostinho[a,*], Cecília M.V.B. Almeida[a], Biagio F. Giannetti[a]

[a] Paulista University (UNIP), Post-Graduation Program in Production Engineering, Brazil
[b] Mackenzie Presbiterian University, Brazil
[c] "Armando Alvarez Penteado" Foundation (FAAP), Brazil

ARTICLE INFO

Keywords:
Brazil
Green building rating systems
LEED
Sustainable buildings

ABSTRACT

Green labels have strong potential in identifying buildings with lower load on the natural environment, among which the leadership in energy and environmental design (LEED) is the most used certification worldwide. LEED's potential in truly reflecting a building's sustainability degree has been receiving criticisms in the scientific literature. The more recent LEED versions represent, in theory, improvements over the previous ones in an attempt to overcome such criticism. This work assesses the way in which LEED certification is pushing buildings towards higher sustainability degrees. Primary data are based on the Brazilian certified buildings up to 2016, totalizing 276 projects evaluated under statistical approaches, including the Kruskall Wallis analysis, credit achievement degree, and skewness indices. Results show that energy & atmosphere and material & resource categories received lower scores among all other categories for the 2009 LEED version than for the 2.0/2.2 version. The 2009 LEED framework allowed the certified Brazilian buildings to pursue those easier-to-obtain scores, which raises doubts about whether the LEED label push to strong sustainability since its core concept is based on energy and material consumption. Notwithstanding, the evaluated projects in Brazil pursue lower degrees of sustainability because they apply efforts in obtaining the minimum scores required by a specific label. Although demanding improvements, LEED certification should be promoted as an important tool towards sustainable development due to its innumerous advantages.

1. Introduction

Sustainability is increasingly being considered a fundamental aspect on decisions in anthropic production systems, due to growing concerns on biosphere ability in providing resources and diluting byproducts (Meadows et al., 1972; Wackernagel and Rees, 1996; Odum and Odum, 2001; Rockström et al., 2009). In regard to Earth's biocapacity reduction, different problems arise, such as those related to global warming and the reduction of resources availability to support societal development, including agriculturable soil, potable water, ground-basic minerals, and fossil energy. The "strong sustainability" concept, which is the main goal of this paper, refers to a non-substitutability of man-made for natural capital (Neumayer, 2003), in other words, there are thermodynamic restrictions to growth. The United Nations Environment Program for Sustainable Buildings and Construction (UNEP, 2018) highlighted that buildings life cycle consumes about 40% of global energy and 12% of potable water, besides being responsible for about 30% of global energy-related greenhouse gas emissions and generating 40% of the world's solid waste. These figures emphasize the need for alternatives for the construction and usage of buildings, and the green labels can be considered an important tool to assure higher degrees of sustainability for the building sector.

Green building certifications are disseminated worldwide. Certifications play an important role in complementing sustainability assessment tools providing information among stakeholders through simplified communication and early introducing sustainability aspects in the planning process (Wangel et al., 2016). For example, Berardi (2017) points out that the total building energy consumption in BRIC countries (Brazil, Russia, India and China) has overcome those in developed countries, and the continuous increase building projects creates an urgency for promoting building energy efficiency policies. Illankoon et al. (2017) emphasized that green building rating tools are developed to provide a yardstick for measuring green building performance. As well as for other developing countries, Nguyen et al. (2017) claims that the most challenges obstacles in implementing

* Corresponding author at: Universidade Paulista (UNIP), Programa de Pós-Graduação em Engenharia de Produção, Laboratório de Produção e Meio Ambiente, Rua Dr. Bacelar, 1212, 04026-002, São Paulo, Brazil.
E-mail address: feni@unip.br (F. Agostinho).

https://doi.org/10.1016/j.resconrec.2019.02.037
Received 16 July 2018; Received in revised form 22 January 2019; Accepted 25 February 2019
0921-3449/

green buildings in Vietnam are social and cognitive barriers, including legislative and institutional ones. According to Suzer (2015) and Shad et al. (2017), the chronological evolution for green labels in the building sector began with certification of attendance levels. The first label came to light in the United Kingdom issued by the Building Research Establishment Environmental Assessment Method (BREEAM) in 1990, followed by the Leadership in Energy and Environmental Design (LEED) in 1998 in the United States of America (USA), the Green Standard for Energy and Environmental Design (G-SEED) in 2001 in South Korea, the Comprehensive Assessment System for Built Environment Efficiency (CASBEE) in 2002 in Japan, the Green Building Tool (GBTool) in Canada, and, finally, the Green Star in 2003 in Australia. Some of them are local or regional specific, while others are used internationally.

LEED is both the most popular and most widely used green building rating system worldwide (Shad et al., 2017). Assessing the LEED residential market adoption in USA, Rakha et al. (2018) have found that its growth has strong relationship with GDP per capita, number of LEED accredited professionals per capita, and the amount of green policies and incentives. These results reinforce the findings of Zhao and Lam (2012) when assessing the influential factors (population, policy and accredited professionals) in the adoption of LEED building in USA. Although developed to accomplish for the USA characteristics, the LEED has no restrictions for use in other countries, but the lack of a more flexible framework could be considered an operational limitation for its general usage. For instance, Suzer (2015) assessed the problems in using LEED v.4 worldwide without adjustments with respect to local geographical, cultural, economic and social parameters. Results showed some inadequacies and inconsistencies in using LEED, specifically, in the environmental concerns prioritization for projects sensitive to this issue. The author suggested that correctly establishing the environmental concerns priorities could result in more precise results, since the building project is inserted within its environment. Alyami and Rezgui (2012) also emphasize the importance of a weighting framework as key element in the philosophy of point allocation in green building rating systems. Cidell and Beata (2009) highlighted the need for more spatially sensitive certification standards by envisioning that newly constructed buildings may have reduced impact on environment, independently on where they are located. Gurgun et al. (2016) reviewed the practices of energy and atmosphere categories of LEED v.2009 new construction (NC) in European countries (including 20 countries and 189 projects) to assess the LEED usage outside USA. Results showed that using LEED in other countries could be difficult because local conditions and practices have influence in obtaining scores. Mousa and Farag (2017) considered a sample of 25 LEED certified projects to verify the applicability of LEED-NC rating system in the Middle East countries. Authors argued that most credit ratings are derived from codes and regulations based on USA standards, making it difficult to fulfill all LEED requirements and leading entrepreneurs to fail in achieving any credit. The main complications perceived were related to material & resources and energy & atmosphere categories.

Additionally to the operational limitations that could difficult the LEED's usage in different regions of world, some authors have identified aspects related to its implementation and meanings, raising doubts about its real ability in representing building's sustainability. For instance, Dekkiche and Taileb (2016) highlighted the importance in integrating life cycle assessment (LCA) within the LEED rating systems to better represent the degrees of sustainability. This suggestion was previously supported by Humbert et al. (2007), who recommended a new LEED scoring system based on LCA to provide proportional scores closely related to the environmental benefits associated with the implementation of each credit. In the same line thinking, Gelowitz and MacArthur (2018) highlight the importance in using environmental products declaration (EPDs) to support the achievement of LEED v4 material credits. Because EPDs are based over the life cycle of a product, authors argue that EPD would bring great benefit to the green building industry due to its higher transparence in providing environmental claims than others available environmental documents. Kubba (2016) emphasized that weighting preferences in the LEED 2009 system were focused on energy, which was considered appropriate and strictly related to sustainability. However, Wangel et al. (2016) argued that LEED lacks a relative understanding of sustainable development, disregarding upstream and downstream impacts and highlighting a disproportional large number of non-mandatory issues that makes benchmarking difficult and allows sustainability aspects to be exchangeable. These authors declared that a project could be certified without being sustainable (such as projects with scores in the lower level limit and projects that obtained low scores for both EA and MR categories). Similar results were found by Newsham et al. (2009), which claim for efforts from LEED developers in rethinking about the green building rating schemes to ensure that energy performance of the certified buildings has higher correlation with certification levels. Complementarily, Scofield (2009) stated that LEED's framework should consider physical averaging techniques for allocation purposes in large buildings to avoid that inefficient buildings in using energy receive LEED certification. Wu et al. (2016) argued that low credit achievement degree for EA and MR categories may be one of the reasons to the credit changes in LEED 2009, but they also found evidences that scores achievement for both categories remain low. Wu et al. (2016) emphasized the importance in recognizing regional/local characteristics within the LEED framework, in which aspects such as more ecologic building projects, cleaner production, and the use of renewable energy sources should be recognized and included in the rating system. Illankoon et al. (2017) suggested the development of new rating tools or the improvement of the already existing ones, so as to allow for a criterion to receive similar attention avoiding the point-chasing behavior and resulting in a balanced score system that better represents sustainability.

LEED's developers attempt to improve its framework through each launched version, seeking for a more accurate representation of the sustainability concept. However, before proposing alternatives for improvement, it is fundamental the identification of LEED shortcomings. Specific studies were carried out to identify how the certified LEED projects are getting their labels, precisely, which categories are being fulfilled in lieu of others and the reasons for this score-chasing tendency. The work of Ma and Cheng (2016) provided a better understanding in obtaining credits by LEED-NC v.2009 certified projects. Credits for some aspects like rapidly renewable materials (MRc6) and materials reuse (MRc3) were seldom found in certified projects because they are very difficult to achieve; the same applied to optimize energy performance (EAc1) and on-site renewable energy (EAc2), which demand efforts and economic investments to be obtained. Other important studies were performed by Wu et al. (2016, 2017), who evaluated the use of LEED v.2.2 and v.2009 certified projects around the world. The authors observed that both alternative compliance path (ACP) and regional priority credits (RPC) categories could help in reducing the disparities of regional differences on certified projects. Precisely, 5340 projects were considered in their analysis, from which 34 projects were from South America, suggesting that more studies on this region should be performed to verify whether the LEED score tendencies observed for other regions are similar to those found for South America certified buildings. Statistical techniques were used to assess the allocation pattern of scores. For the v.2.2, results showed that the easiest category to obtain scores is innovation (INN), while energy (EA) and materials (MR) categories are the most difficult ones. For the v.2009, results showed that point chasing on INN category was softened, but EA and MR remained the most difficult categories in obtaining scores. Wu et al. (2018) ratified these observations by suggesting the unbalanced achievement a problem of point-chasing, which claims for a redesign of regional priorities credits.

Efforts towards the advancement of LEED in better representing sustainability and be accepted worldwide are being made. In theory, theses advancements can be identified by the different LEED versions published, including the 1, 2.0, 2.2, 2009, and the more recent version 4. According to the US Green Building Council (USGBC, 2018), “LEED is continuously evolving and improving”, “moving in the right direction”, and every new LEED version represents an “evolution” over the previous versions. New versions attempt to overcome the identified operational limitations in the previous ones, aiming to become a more flexible and adapted tool to the different regions of the world, and more aligned with the sustainability concept. Some works suggested changes in the LEED framework to increase its robustness in evaluating green buildings. For instance, Champagne and Aktas (2016) have found gaps that could have overcome by updating the regional priority LEED category. It is suggested that LEED 4 should encompass resilience as a requirement by revising the site assessment, rainwater management, and overhaul regional priority that includes climate projections rather than historical data. Jun and Cheng (2017) proposed a method to predict the credit achievements for the existing LEED building (EB) v.2009 projects using data mining techniques. They developed a web-based decision support system for LEED credit selection. Michael et al. (2017) propositioned a multi-objective model to optimize retrofitting costs, energy, savings, water savings, payback period, and points related to the LEED rating system. These authors argued that the proposed model is efficient in optimizing retrofit plan, while collaborates towards a green building certification. Donghwan et al. (2015) emphasized that certified LEED buildings have no influence on regional climate. Authors argued about the need of a systemic thinking within LEED to become a true sustainable building standard by considering the local environment where the certified buildings are located, relating urban problems with the architectural building performance.

Understanding that strong sustainability is the core concept to support any development planning, its correct representation plays crucial issues that deserve attention by LEED developers and users. In this sense, aiming to collaborate towards a more robust LEED certification framework, the main goal of this work is to assess the way in which LEED is pushing the Brazilian certified buildings towards sustainability. Complementary to the works of Ma and Cheng (2016) and Wu et al. (2016, 2017, 2018), this work considers the Brazilian projects as case study because few samples representing this particular country has being used; precisely 34 projects in South America were accessed by Wu et al. (2016), and not all of them belong to Brazil. This can be considered as a scientific gap since Brazil is a quite different country (culturally, economically, and climatically) compared to United States of America, Canada, the European and Eastern countries as usually considered in sciencitifc studies regarding LEED application. Notwithstanding, instead of considering exclusively average values of LEED scores as usually found in scientific papers, the statistical skewness analysis is here considered to allow a discussion on the tendencies in pursuing LEED scores by the studied buildings. In short, this work is justified by the larger sample considered to updated previous diagnosis about the LEED certified projects in an important and representative country of Latin America, and because it provides a different perspective in assessing scores achievement through the skewness statistical analysis. The certified projects in Brazil are here focused, and statistical tools are used in an attempt to answer the two following research questions derived from the work of Wu et al. (2016): #1 - Are EA and MR categories still receiving lower scores than others LEED categories for the 2009 version? #2 – Is the 2009 LEED version able to better reflect projects with higher sustainability degrees?

2. Methods

2.1. Data source and sample for LEED certified projects

All primary data were obtained from the certified global business registration webpage named green building information gateway (GBIG), available at gbig.org/places/96/activities. Data comprise projects registered up to November 2016 available exclusively for online viewing and not obtainable to download in operational format for further statistical treatment and use. To overcome such issue, a data mining process was implemented to extract data from GBIG. The Google Chrome Browser Data Miner (data-miner.io) was used as support for the data mining process, by extracting and converting web-data into spreadsheets supported by the Microsoft Excel® software.

The data mining procedure identified 322 Brazilian certified projects, from which 276 were chosen as representative for this study (Table 1). The remaining 46 projects were disregarded as they either considered partial items to be certified (e.g. the existing buildings typology), or different LEED indicators compared to those for buildings construction (Neighborhood Development typology), or have different characteristics (schools and sheds). The analysis of Brazilian projects was supported by the work of Wu et al. (2016) concerning the achievement of scores and the distribution skewness approaches. LEED versions 2.0–2.2 and 2009 were selected since no project was certified under versions 1 and 4 up to November 2016. Typologies selected were commercial interiors (CI), core and shell (CS), and new construction (NC), as they represent 86% of total. Detailed information on each of the 276 individual projects are presented in Tables S1 (Supplementary Material), including the city where the project was implemented, the project name, the LEED typology and version, and awards including grade, year, and all the evaluated categories.

Table 1
Total projects certified by LEED in Brazil by October 2016.
Source: GBIG (2016). Legend: ID + C = Interior Design and Construction; BD + C = Building Design and Construction; O + M = Building Operations and Maintenance.

LEED typology		LEED version	Total of projects certified
Number of projects considered in this study = 276			
Commercial Interiors (CI)	ID + C	2.0	6
	ID + C	2009	30
Core and Shell (CS)	BD + C	2.0	28
	BD + C	2009	110
New Construction (NC)	BD + C	2.2	19
	BD + C	2009	83
Number of projects not considered in this study = 46			
Existing Buildings (EB)	O + M	2008	2
	O + M	2009	24
Neighborhood Development (ND)	Plan	2009	3
Retail CI	ID + C: Retail	1.0	7
	ID + C: Retail	2009	3
Retail NC	BD + C: Retail	2009	3
School	BD + C: Schools	2009	2
Home	BD + C: Homes	2008	1
New Construction (NC)	NC	2007	1
Total of Brazilian projects certified by LEED = 322			

LEED version 2.0–2.2 categories comprehend sustainable sites (SS), water efficiency (WE), energy & atmosphere (EA), materials & resources (MR), indoor environmental quality (IEQ), and innovation (INN); for the 2009 version, regional priority credits (RPC) was included. Tables S2 (Supplementary Material) provide all primary data for categories and their respective maximum scores for each typology and version. As more complete data is made publicly available, more robust will be the findings and more comprehensive the discussions, however, the best data currently available were used in this work.

Due to the large amount of acronyms used in this work, the following main nomenclature is adopted, in accordance with LEED office standards:

(a) Typology includes commercial interiors (CI), core and shell (CS) and new construction (NC);
(b) Version includes 2.0.-2.2, and 2009;
(c) Category includes sustainable sites (SS), water efficiency (WE), energy & atmosphere (EA), material & resources (MR), indoor environmental quality (IEQ), innovation (INN), regional priority credits (RPC), and alternative compliance path (ACP);
(d) Level includes certified, silver, gold, and platinum.

2.2. Data analysis

The considered Brazilian LEED certified projects include CI and CS for

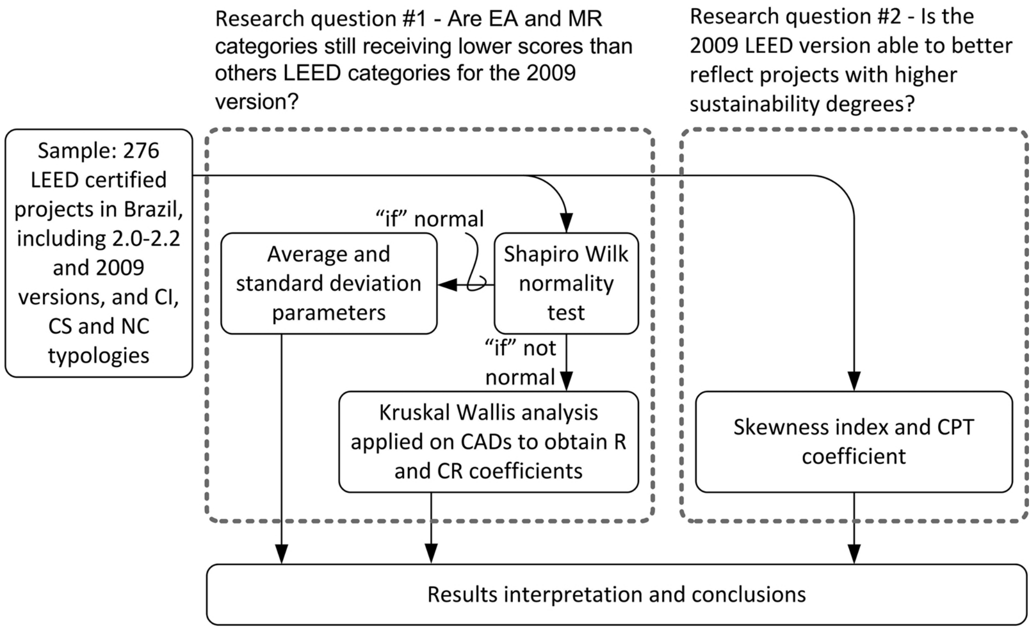

Fig. 1. Schematic representation of data analysis procedure as used in this paper. Legend: CI, commercial interiors; CS, core and shell; NC, new construction; EA, energy & atmosphere; MR, material & resources; CAD, credit achievement degree; R, rank value; CR, coefficient of rank; CPT, credit per track.

2.0 and 2009 versions, and NC for 2.2 and 2009 versions. The sample consisting of 276 projects was assessed under the following sequence of statistical procedures (Fig. 1) to support a scientific-based discussion:

(1) Identify the probability distribution function representing the sample to verify whether it follows a normal curve function (i.e., a Gaussian curve). When normal, it is justified to determine probabilities associated to sample through two simple parameters: average and standard deviation. The Shapiro Wilk (known as the W test) normality test was being recommended by the United States Environmental Protection Agency (USEPA, 2000) as the most recognized and used test in scientific works. For this, the null hypothesis H0 (sample can be represented by a normal distribution) is verified under a statistical significance level of 0.05 for each LEED version and typology. When the calculated "W value" is lower than the "W critical", the null hypothesis H0 is rejected and the average and standard deviation of sample cannot be directly used.
(2) When the distribution function is not Gaussian, the Kruskal Wallis analysis statistical inference (called as KW test) was used. The KW test was applied into two samples, aiming to compare their median values (USEPA, 2013). The influence of LEED categories on total obtained scores was analyzed by correlating pairs of categories to identify which one presents higher average value. Scores were parameterized by using the expression denominated by Wu et al. (2016) as Credit Achievement Degree (CAD): CAD = CO/TO; where CO is the credit obtained by a category (the score obtained in LEED) and TO means the total score of LEED category. Then, the KW test was applied to CADs values resulting in the rank value (R) and coefficient of rank (CR), which enabled to identify how scores are being obtained, or whether a specific category is receiving more importance/scores than others. A higher R-value for a category indicates higher influence or representativeness within the sample, while CR represents the normalized values of R (the ratio between R and maximum R among categories). These indicators were used to assess whether energy & atmosphere (EA) and materials & resources (MR) categories are receiving lower scores than the others. The premise assumed for this analysis is as follows: the quest for a strong sustainability (Neumayer, 2003) must consider the thermodynamic restrictions for growth, in other words, energy and material consumption by buildings must mandatorily receive higher attention than all other LEED categories.
(3) The skewness (SKW) index was used to represent the asymmetry (the distance between average and median values) of the probability distribution curve for LEED scores for each category, typology, and version. Negative SKW values indicate that curve's tail on the left side of the probability function is longer than on the right side, while positive SKW indicates that the curve's tail on the right side is longer than on the left side; a zero value means a symmetrical distribution. SKW closer to zero indicates that the certification market works uniformly to obtain the LEED label; higher positive or negative SKW indicates that certification market works non-uniformly, as a larger number of buildings are obtaining lower (-SKW) or higher (+SKW) scores within the same LEED level. Additionally to the SKW index, the Credit per Track (CPT) was also calculated through the expression: $CPT = CO/TO_{max}$; where CO is the credit obtained by a category and TO_{max} is the maximum theoretical score for each LEED typology and version. The average and median values for CPT reflect the participation of each category on the maximum possible score. The average, median and distortion of scores distribution obtained by each LEED level were also analyzed to assess whether there is a tendency in pursuing the highest or lowest scores within a LEED level, or whether a certified building that received a gold label reached scores close to minimum or maximum values as allowed by LEED for gold level.

The premise assumed for this analysis is as follows: the quest for sustainability can be expressed by the skewness index (SKW) within the same LEED level, i.e. greater than zero for the SKW indicates efforts to obtain higher scores and, consequently, efforts towards higher sustainability degrees than the sample average.

3. Results and discussions

3.1. Statistical normality test for data distribution

Table 2 shows the results for the normality test, indicating that score performance for most of the certified buildings considered in this study do not follow a Gaussian distribution function. EA and IEQ categories were the ones with higher Gaussian behavior (three for both), while all others showed a non-normal distribution behavior, especially for WE, INN and RPC. Taking into account both the evolution of LEED version

Table 2
Normality test according to Shapiro-Wilk method.

LEED typology	LEED version	Certified projects	Categories						
			SS	WE	EA	MR	IEQ	INN	RPC
Commercial Interiors (CI)	2.0	6	No	no	normal	normal	normal	no	–
	2009	30	no	no	normal	no	normal	no	no
Core and Shell (CS)	2.0	28	normal	no	normal	no	no	no	–
	2009	110	no	no	no	no	no	no	no
New Construction (NC)	2.2	19	normal	no	no	no	normal	no	–
	2009	83	no	no	no	no	no	no	no

Results with a significance level of 0.05; RPC category were not identified for old LEED versions 2.0–2.2.; Detailed calculation at Tables S3 (Supplementary Material).
Legend: SS = sustainable sites; WE = water efficiency; EA = energy & atmosphere; MR = material & resources; IEQ = indoor environmental quality; INN = innovation; RPC = regional priority credits.

from 2.0 to 2.2. to 2009 simultaneously with a higher number of samples, a tendency for non-normality for all categories can also be noted; see, for instance, CS 2009 with a sample consisting of 110 certified buildings tending to non-normality.

Differently from the results obtained by Wu et al. (2016) that showed a non-normal distribution for the entire sample considered by authors (around 5000 certified buildings), Table 2 shows a normal behavior for some categories and typologies for the assessed Brazilian projects. This difference could be addressed to the lower amount of samples for the Brazilian building certifications (276 certified buildings); maybe, a higher amount of certified buildings considered as sample could show a similar behavior as that found by Wu et al. (2016). Due to an overall observed non-normality behavior for the samples (Table 2), the use of statistical inference instead of directly working with average and standard deviation values becomes mandatory. The Kruskall Wallis test (KW test) was then applied to the samples showing both normal and non-normal behavior since it has no restriction (Portal Action, 2016).

3.2. Verifying the "point-chasing" of categories on total scores

The point-chasing analysis aims to identify which categories are most relevant or which ones have higher influence on total scores obtained by the Brazilian certified buildings. This section assesses whether EA and MR are receiving lower or higher scores than others.

From the KW test available in detail on Tables S4 (Supplementary Material) it is possible to analyze the performance in obtaining scores among LEED typologies, versions and categories. Results are summarized in Table 3. The categories INN, WE and SS appear under the same sequence of importance in getting scores for the initial versions 2.0.-2.2, while the position of MR was changed for NC. As observed by Wu et al. (2016, 2017), innovation (INN) stands out in 2.0–2.2 version because it is easier (both operationally and economically) to obtain scores for this category than for all others. Before INN, the WE and SS categories are present, which may be justified by the water restrictions in Brazil a few years ago, which demanded higher efforts on these categories, or even due to project implementation conditions. Similarly to results obtained by Wu et al. (2016), the EA category is located in the last positions, along with IEQ, which indicates that buildings in Brazil have a strategy to obtain LEED scores seeking to meet the requirements of categories that require less time and money investments. In this context, an obligatory question arises: Why should a company spend more money and time to obtain a certain amount of LEED credits if the same credits can be obtained under an economic and time saving way? The practice in obtaining the easiest scores by applying basic technology and/or the lowest economic investment become the target (reflected by the position of INN, WE and SS categories on Table 3) in opposition to the central objective of the Leadership in Energy and Environmental Design (LEED), which promotes energy reduction and lower environmental load.

According to Kubba (2016), energy and resource conservation are the general logic behind the design and construction of a green building project. Shan and Hwang (2018) also emphasize the energy criterion as the most important in the LEED framework. However, for cases when a building project has reached a more efficient use of energy, LEED allows an allocation procedure for scores into EA or INN, and other categories depending on specific features. Considering that EA usually demands more operational and economic costs to certify an increase of its efficiency (Jalaei and Jrade, 2015), LEED users prefer to allocate the obtained scores in the INN category because it will demand a smaller amount of documents, time, and money. In this scenario, EA and other important, but high cost categories (Dwaikat and Ali, 2016), are left as a second option. Understanding that a building should not be certified

Table 3
Performance for LEED categories in accordance with the Kruskal-Wallis rank coefficient (CR; numbers in parentheses).

LEED typology and version	Categories* in order of scores achievement represented by the CR coefficient in parentheses						
	1st	2nd	3rd	4th	5th	6th	7th
CI 2.0	INN[1,2,3,4] (1.00)	WE[1,2,3,4,5,6] (0.90)	SS[1,2,3,4,5,6] (0.66)	MR[1,2,3,4,5,6] (0.56)	IEQ[2,3,4,5,6] (0.36)	EA[2,3,4,5,6] (0.33)	–
CS 2.0	INN[1,2,3] (1.00)	WE[1,2,3] (0.92)	SS[1,2,3,4] (0.70)	MR[3,4,5,6] (0.48)	EA[4,5,6] (0.28)	IEQ[4,5,6] (0.26)	–
NC 2.2	INN[1,2,3] (1.00)	WE[1,2,3] (0.97)	SS[1,2,3,4,5] (0.69)	IEQ[3,4,5,6] (0.39)	MR[3,4,5,6] (0.37)	EA[4,5,6] (0.23)	–
CI 2009	RPC[1,2,3,4] (1.00)	WE[1,2,3,4] (0.92)	INN[1,2,3,4] (0.90)	SS[1,2,3,4] (0.88)	EA[5,6,7] (0.55)	MR[5,6,7] (0.29)	IEQ[5,6,7] (0.28)
CS 2009	RPC (1.00)	INN[2,3,4] (0.81)	WE[2,3,4] (0.70)	SS[2,3,4] (0.70)	MR[5,6,7] (0.44)	IEQ[5,6,7] (0.36)	EA[5,6,7] (0.33)
NC 2009	RPC[1,2,3] (1.00)	INN[1,2,3] (0.92)	WE[1,2,3] (0.92)	SS (0.65)	MR[5,6,7] (0.37)	IEQ[5,6,7] (0.32)	EA[5,6,7] (0.27)

* Detailed numbers are presented on Tables S4 (Supplementary Material); Same superscript numbers means that average for score values of a category within the same typology and version are statistically similar; Legend: SS = sustainable sites; WE = water efficiency; EA = energy & atmosphere; MR = material & resources; IEQ = indoor environmental quality; INN = innovation; RPC = regional priority credits.

as green by LEED when those categories strictly related to the LEED's central concepts and principles have lower scores than all other categories, a revision on the allocation procedure for scores is required.

Table 3 shows that typologies CS and NC for the 2009 version are equivalent in priority of attendance, indicating that the market tends to pursue higher scores for RPC and INN, maybe due to the reasons previously described, related to practicality. Categories WE and SS come next, maybe due to the water issues faced in Brazil a few years ago and to the strategic city planning in regards to infrastructure. For the CI 2009, there is a slight change in the first positions where INN is replaced by WE, although their CR values (0.92 and 0.90 respectively) do not indicate statistical differences. The last positions for 2009 version are MR, IEQ, and EA for both CS and NC typologies, while CI has a sequence of EA, MR, and IEQ. Although understanding that these three categories should receive higher scores as they are strongly related to LEED objectives to achieve sustainability, an opposite scenario emerges, indicating that the certification market in Brazil is focused on getting higher scores for the simplest and lowest cost categories. This highlights that EA and MR categories are not prioritized, which is in accordance with the results obtained by Wu et al. (2016) and places Brazilian outcomes in equivalence with the international scenario.

To evaluate the dynamic scores over LEED versions, the categories for the same typology are now considered to support a discussion. For CI 2.0, Table 3 shows that INN is the category with the highest score followed by WE, whereas the last positions are occupied by EA and IEQ. Recognizing that the electricity matrix in Brazil is mainly derived from hydropower (considered cleaner than the fossil-based energy), the certified buildings should allocate their obtained scores relative to energy aspects on EA and/or MR categories instead of INN or any other one allowed by the LEED framework. However, this will hardly happen, due to higher cost (Dwaikat and Ali, 2016), and amount of time and documents demanded (Jalaei and Jrade, 2015). As also identified by Wu et al. (2016), the RPC category for CI 2009 received higher scores, followed by WE, while IEQ and MR are in the last positions with a CR value about 50% lower than EA (0.28, 0.29, and 0.55 respectively). This indicates that the evolution from the 2.0 to the 2009 version for CI resulted in a worse performance for MR, by reducing its CR from 0.56 to 0.29, while the CRs for EA and SS were increased (0.33-0.55 and 0.66-0.88 respectively).

Focusing on CS 2.0, the INN category was the one with the highest scores followed by WE, although they are statistically similar; next, there are SS, MR, EA and IEQ. Disregarding INN, the WE category is receiving again high efforts, maybe due to water constraints in Brazil. The insertion of RPC in the CS 2009 version moved INN to the second position in scores received, indicating that RPC received higher efforts than INN in obtaining scores maybe due to the same reasons of lower time demand, lower expenses, and less bureaucracy. CR indicates that SS remained almost constant (0.66 – 0.70), while WE showed a reduction of 20% between the 2.0 and the 2009 LEED versions for CS (from 0.90 to 0.70); similar behavior is observed for the MR category, but in lower proportion (from 0.56 to 0.44). As observed by Wu et al. (2016), the certification evolution from CS 2.0 to 2009 resulted for the RPC as the category with the highest score, followed by INN, while EA and IEQ contribute little to the total score for CS typology.

The NC 2.2 typology presents INN as the category with the highest scores, followed by WE, SS, IEQ, MR and EA. Again, INN appears as the top category for the same previously discussed reasons. As for the 2009 version, the inclusion of RPC attracted high amount of scores, which placed it in the first position among all categories. Comparing NC 2.2 and 2009, it can be observed that INN was replaced by RPC, that according to personal communication with some LEED users in Brazil, it is even easier to obtain scores for RPC than for INN; as also observed by Wu et al. (2016). As identified for CI and CS typologies, the EA has the worst performance for NC, indicating lower efforts in obtaining scores for this category.

In general, the LEED versions evolution from 2.0 to 2.2 to 2009 was not able to show a significant change in the scores distribution among categories. The highest scores that, at principle, should be allocated to EA and MR categories so as to be better aligned with the strong sustainability principles were not observed as having been so. Although an increase in scores can be observed for EA and MR over LEED versions (Tables S2 – Supplementary Material), it was not sufficient to place either one closer to those categories with the highest scores (RPC, INN and WE). According to the methodological premises established in this work, these aspects indicate that buildings are not pursuing higher degrees of sustainability; this can be a result of individual projects preference or even the inability of LEED in pushing projects to achieve such a goal. A balance of scores among categories was also not observed. The obtained results support that EA and MR categories are still obtaining lower scores for 2009 LEED version than all other LEED categories.

Illankoon et al. (2017), Doan et al. (2017), and Mattoni et al. (2018) agreed that energy, material, water, and indoor environmental quality are the top four aspects considered by the existing green building rating tools (including LEED), which means they are recognized as strongly related to sustainability. Although the effort of LEED developers in assigning more scores for EA and MR categories along the LEED updated versions (Tables S2 – Supplementary Material), the results of this present work show that EA, IEQ and MR are the categories with lower scores; this characteristics was also observed by other researchers (e.g. Wu et al., 2016, 2017). If EA and MR are recognized as fundamental in representing a strong sustainability, how can they still receive lower scores for the advanced LEED 2009 compared to 2.0–2.2 version? A potential answer is related to costs (as emphasized by Dwaikat and Ali, 2016) and other operational difficulties in getting more scores for EA and MR categories than for others (as discussed by Jalaei and Jrade, 2015), also because LEED allows that buildings with lower scores for both categories receive the green label. This behavior is usual, even though savings resulting from a green building life cycle overshadow the incremental cost to achieve a green building (Vyas and Jha, 2018). Illankoon et al. (2017) also observed the possibility of certification by fulfilling one particular criterion, even though all the other key credit criteria are overlooked or even completely ignored. Thus, LEED framework should advance towards avoiding an unbalance of obtained scores among categories, or even require that those categories closer aligned with sustainability principles (i.e. EA and MR) receive, mandatorily, higher scores (besides the prerequisite credits already established). LEED developers made efforts in this direction mainly for EA that, for example, jumped from 22% to 33% of total scores representativeness for CS, although the importance of MR was reduced from 18% to 12%. Other interesting example is provided by Jalaei and Jrade (2015) that integrated the building information modeling into the LEED system aiming to reduce documentation needs (including time) and costs for LEED users. Anyhow, additional efforts are still missing towards a scoring framework that push buildings to obtain higher scores, mainly for those categories closely related to the concept of strong sustainability.

3.3. Assessing scores achievement

According to the objectives of this analysis and to facilitate interpretation, the scores achievement assessment is focused on the three typologies (CI, CS, and NC), separately. From the evolution of CI 2.0 to 2009, Fig. 2 (please also refer to the numbers of Tables S5 Supplementary Material) indicates a slight improvement for the gold level, from 58% to 62% in fulfilling the maximum score. Its SKW is closer to zero (from −0.85 to −0.05), indicating that differences between average and median score values of the sample were reduced, and that market practice in obtaining scores was uniform in 2009. However, Fig. 2 shows a SKW different than zero (-0.51 and 0.17) respectively for them in the 2009 version, which indicates a non-uniformity for market in getting scores; in other words, while some projects make strong efforts in obtaining scores, others apply minimum efforts to be certified. For CI 2009 platinum, the SKW presents high negative values (-0.56) by reaching about 78% (score of 87) of the total possible score, which ranges from 40 to 110. Besides reflecting non-uniformity by the market, this SKW indicates that buildings certified as LEED platinum have a

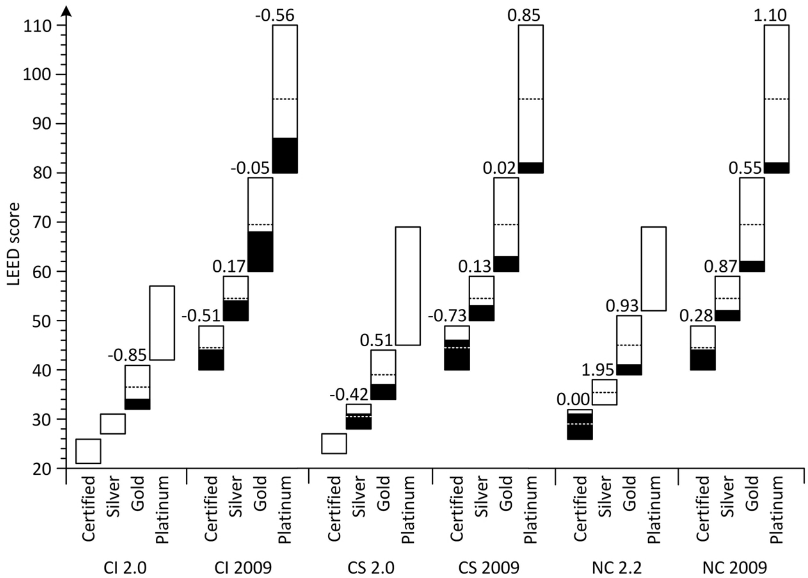

Fig. 2. Achieved scores by the Brazilian certified projects according to different LEED levels, typologies, and versions. Legend: Dashed lines represent the theoretical average value for each level; Median values for the real score obtained in each level are represented by the black color; An empty white box (i.e. with no dashed lines or black color regions) means the absence of a certified project or a reduced sample that is considered insignificant for statistical analysis; numbers above bars indicate the skewness index (SKW). Detailed numbers are presented on Tables S5 (Supplementary Material).

tendency to obtain the minimum scores to reach such certification level. Other important aspect to be observed in Fig. 2 is related to the theoretical level average as symbolized by the dashed lines. In general, none of the LEED levels was able to reach its theoretical average value, confirming that buildings apply minimum efforts to be certified. The SKW of 0.17 for the CI 2009 silver stands for the existence of a certain number of certified buildings applying efforts to achieve higher scores closer to silver level's upper limit. An opposite situation rises for the certified and platinum levels CI 2009 with SKW of -0.51 and -0.56, respectively, which indicates the absence of efforts towards higher scores and, analogously, that buildings are not pursuing higher sustainability degrees.

For the CS typology, there are buildings labeled as silver (8) and gold (18) in the 2.0 version, which makes them able to be statistically compared against their 2009 version; for certified (1) and platinum (1) levels, there is an insufficient number of samples (detailed numbers on Tables S5 Supplementary Material). Fig. 2 shows that silver CS 2.0 and certified CS 2009 have average scores higher than their theoretical average level value, however, their SKW of -0.42 and -0.73 indicate the existence of companies pursuing minimum scores, which attract the sample average value to inferior limits. This indicates a non-uniformity of market in obtaining scores and that some companies are pursuing low degrees of sustainability or just the label. All other levels in the CS obtained scores below the theoretical level average, but their positive SKW indicates a tendency in pursuing higher scores beyond the sample average; this aspect can be observed mainly for platinum CS 2009 and gold 2.0 certified buildings with SKW of 0.85 and 0.51 respectively.

Focusing on NC, Fig. 2 shows that platinum 2.2 level has no certified buildings (detailed numbers on Tables S5 Supplementary Material). The certified 2.2 level was the one that achieved sample average higher than its theoretical average, indicating that these buildings obtained high scores and closer to the upper limit. Additionally, the SKW for certified level of 0.00 indicates a uniform practice by the market in pursuing high scores. These two characteristics are seen as positive and reflect a search for higher degrees of sustainability. However, the NC 2009 has a different behavior, with a sample average below its theoretical average with SKW of 0.28; this indicates non-uniformity by the market in achieving scores, but a tendency towards higher scores for some certified buildings within the sample. With the exception of level certified 2.2, the following behavior is repeated for all others NC levels: sample averages for scores are lower than their theoretical average; there is non-uniformity in the market to achieve scores; and there is a tendency in pursuing scores beyond the sample average because SKW > = 0.

In summary, Fig. 2 shows that scores obtained by certified buildings are usually closer to the inferior limit required by each LEED level so that the minimum scores are being obtained to be certified. This implies that, according to our initial premise, the certified buildings are not pursuing higher degrees of sustainability, and that LEED procedures allow them to do it. According to Doan et al. (2017), "green rating systems have been under constant updates to follow the sustainable trend of building development", and their framework "tend to be more comprehensive in order to completely assess the sustainability of a project". Despite understanding the rationale of Doan and coworkers, Fig. 2 shows an opposite interpretation, at least for the Brazilian certified buildings. It seems clear that buildings usually make minimum efforts to obtain a label due to the possibility of receiving a LEED label according to a range of possible scores (upper and lower limits). For instance, a building that received a gold level certification with high scores and closer to upper limit allowed by this level has similar performance compared to a building that received a platinum level certification by scoring closer to its inferior limit; thus, the efforts done by the former in pursuing high scores is not properly recognized. The existence of such flexibility within the LEED framework hardly will push projects in pursuing higher degrees of sustainability, under a holistic perspective; instead, they do pursue LEED certification mainly for other purposes, such as market acceptance. We understand that LEED has merit while it identifies different levels of certification through labels certified, silver, gold and platinum recognizing the effort of projects in pursuing higher scores and, consequently, higher degrees of sustainability. However, some issues appears, for instance, what the certified building with minimum scores for platinum did more than the certified building with maximum score for gold label? Score ranges in LEED should be reconsidered to properly reward buildings that pursue sustainability.

Additionally to the previously scores achievement analysis, Fig. 3 provides a picture of the assessed certified buildings in relation to their dynamics for SKW index. In general, there is non-uniformity (i.e. SKW far from zero) among the certified buildings in obtaining scores for the same LEED level. The MR 2.0–2.2 showed the best performance amongst all, with SKW more concentrated or with lower range (from -1.0 to 0.5) and values closer to zero; comparatively, INN also showed more concentrated SKW (from -0.9 to 1.75), but its values are far from zero. At the same time, MR and INN categories are the ones with larger differences, when comparing the evolution of LEED versions from 2.0 to 2.2 to 2009, with SKW ranging from 3.3 to -2 and from 2.3 to -2.5 in 2009, respectively. This means that while some certified buildings are pursuing higher scores in the 2009 version, others make minimum efforts to be certified. Amongst all categories, the SS was the one with a

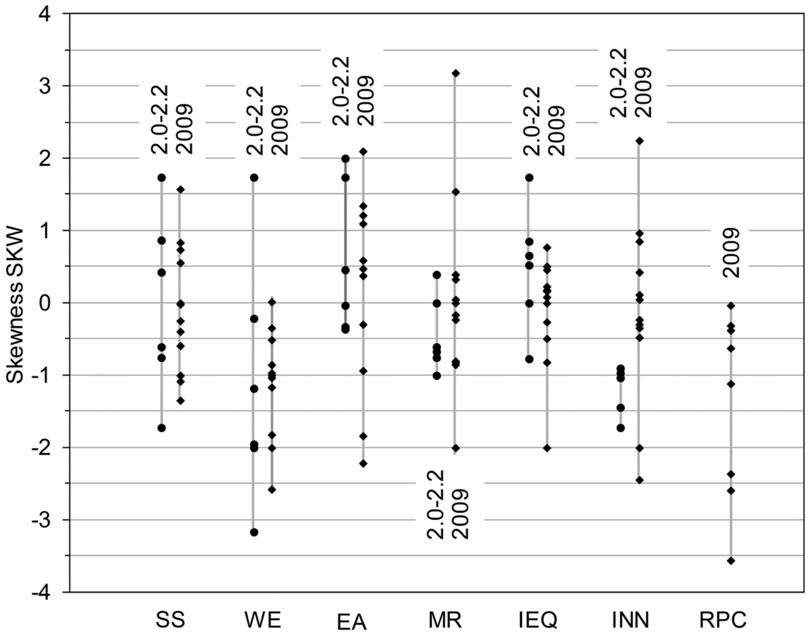

Fig. 3. Skewness index distribution among categories for the two LEED versions studied. Legend: SS = sustainable sites; WE = water efficiency; EA = energy & atmosphere; MR = material & resources; IEQ = indoor environmental quality; INN = innovation; RPC = regional priority credits; Numbers from Tables S5 (Supplementary Material).

similar behavior between versions, including a SKW ranging from -1.7 to 1.7 approximately, and indicating non-uniformity by the market in obtaining scores.

The main outcome of Fig. 3 supports the results of Fig. 2: there is still non-uniformity by the market in obtaining scores for the improved LEED 2009 version. Besides this aspect, the assessed LEED 2009 version was not able to push projects in pursuing higher degrees of sustainability, because there are negative values for SKW indicating that some certified buildings make minimum efforts in achieving scores. A plausible answer for this behavior is as follows: buildings that applied for 2009 LEED version can be certified up to June 2021, thus there will be more than 10 years of advancements in the LEED sustainable-related framework that will hardly be totally incorporated by these buildings. All constructive steps of buildings, including project, implementation and operation will be forced to adapt to the new LEED versions being launched after 2009, which will directly affect the initial projects financial budget. As a result, buildings try to accomplish new impositions of the updated LEED versions by pursuing those scores easier to obtain under both economic and operational aspects. Aiming to overcome this potential problem, Shan and Hwang (2018) suggested the creation of a sustainability rating for those companies/offices specialized in the administrative processes regarding LEED certification. At principle, the work of those most sustainable companies would result in a more complete accomplishment of LEED categories by the certified buildings, directly resulting in higher sustainability degrees.

4. Conclusions

Considering the approaches used in this work and data availability, the conclusions can be derived as follows:

(a) The categories EA and MR received lower scores for 2009 LEED version than for the 2.0/2.2 versions. The advances of LEED 2009 in an attempt to push buildings in obtain higher degrees of sustainability were not able to make EA and MR as important as other categories.
(b) Since the strong sustainability is reflected mainly by energy and material demand, results show that improved LEED 2009 was not able to push the Brazilian certified buildings towards higher degrees of sustainability. This is confirmed when considering the upper limit score within a LEED label level, because buildings usually apply minimum efforts towards achieving the lowest score allowed by the LEED framework to receive a certification within a specific label (including certified, silver, gold, or platinum levels).

It should be highlighted that, as usual in any statistical analysis, the findings of this study can indicate individual projects preferences (usually influenced by both external and internal factors) instead of a pattern. The best data available at the time (amount and quality) were considered in this study, and the analyses applied here should be repeated when a larger sample is available. Both characteristics can be seeing as limitations of this work.

LEED has clear concepts and goals in an attempt to support buildings towards higher degrees of sustainability, by considering a reduction of energy and material demand in the implementation and use building phases. It has strong positive aspects as different certification levels, in an attempt to recognize and award the projects more aligned with sustainability principles. However, our results show that LEED's allocation procedures should be better managed, i.e. within LEED's framework there is room for maneuver, and buildings can be certified even ignoring those categories most important to the strong sustainability concept (energy and materials demand).

Green label is an important tool towards sustainable development, however, some aspects still require attention for improvements, for instance, (i) a balance for scores among all categories could be useful in avoiding the point-chasing approach, or even (ii) rethinking about the range of possible scores within a LEED level (upper and lower limits) to avoid the minimum efforts behavior. This work attempts to discuss some of the above-mentioned aspects of LEED applied to Brazilian buildings, aiming to collaborate in a positive way to improve LEED robustness. We believe that LEED could be scientifically stronger to indicate those buildings that cause lower load on the environment, and that its usage could be spread worldwide to help in achieving the ultimate goal of sustainable development.

Acknowledgements

Authors are grateful for the financial support from Paulista University (UNIP). Thanks also to Westermann M. for his collaboration in the data mining process, Marcelo Succi for his collaboration on statistical analysis, and José Hugo de Oliveira for the English language review. FA is grateful to CNPq Brazil (307422/2015-1).

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resconrec.2019.02.037.

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Glossary

ACP: alternative compliance path
CAD: credit achievement degree
CI: commercial interiors
CPT: credit per track
CR: coefficient of rank
CS: core and shell
EA: energy and atmosphere
IEQ: indoor environmental quality
INN: innovation
LEED: leadership in energy and environmental design
MR: material and resources
NC: new construction
R: rank value
RPC: regional priority credits
SS: sustainable sites
SKW: skewness
WE: water efficiency