SHEARING LAYERS CONCEPT AND LEED GREEN BUILDINGS IN BOTH RATING SCHEMES AND CERTIFIED PROJECTS

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ABSTRACT

The Leadership in Energy and Environmental Design (LEED) for New Construction and Major Renovations v3 (NC) and LEED for Existing Buildings: Operations and Maintenance v3 (EB) schemes were studied to examine the application of the shearing layer concept to green buildings. The manners in which (i) rating systems in their current configurations and (ii) certified projects in their practical applications treated the long life-expectances in buildings and short life-expectancies in systems were questioned. To maximally reduce nondemonic intrusion, we studied only those states in the United States in which statistically viable numbers of projects had been completed in 2016. A two-way mixed analysis of variance (ANOVA) model was used to evaluate the interaction between two types of buildings (i.e., NC vs EB) and two sets of sub-layers (i.e., Site, Structure, and Skin from the Building layer and Services, Space Plane, and Stuff from the Service layer). The discrepancy in the case of a new building and the similarity in the case of a renovated building between rating schemes and certified projects were revealed: (i) the NC rating scheme prefers to emphasize the Service layer (SL), whereas newly constructed projects prefer to emphasize the Building layer (BL) due to the high performance of the Site and Structure sub-layers; (ii) the EB rating scheme prefers to emphasize the Service layer, as do renovated building projects, due to the high performance of the Stuff sub-layer.

KEYWORDS

LEED, new construction, existing buildings, shearing layer concept, green rating system, certified projects

INTRODUCTION

In architectural design, the concept of presenting a building by layers according to their life-expectancy was originally suggested by Frank Duffy (1990), who divided buildings into four layers: Shell (Structure—50 years), Services (e.g., plumbing, heating, ventilation, and air conditioning [HVAC] equipment—15 years), Scenery (partitions, dropped ceiling—5–7 years), and Set (furniture—months to weeks). Duffy (1990) claimed that in initial building design,

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"slow" layers (such as Structure) require more attention from an architect than do "speedy" layers (such as Set) because speedy layers can be replaced quickly, so their initial design is not as important (Duffy 1990). This shearing layer concept was further expanded by Brand (1994), who divided buildings into six layers: Site (eternal), Structure (the foundation and load-bearing elements—50–300 years), Skin (exterior surfaces—20–50 years), Services (e.g., communication wiring, electrical wiring, plumbing—10–20 years), Space plan (interior walls, ceilings, floors, and doors—3–10 years), and Stuff (e.g., chairs, desks, phones, pictures—days to months).

In green rating schemes, the concept of separate treatments for the Building and the System was originally suggested by Shaviv (2011), who claimed that different levels of environmental damage were related to the Building and System due to their different life-expectancies: 50–100 years for the Building and 15–20 years for the System. Consequently, the Energy category of the Israeli Sustainable Standard (SI5281 2011) was divided into two subcategories: Building- and System-related energy performance.

Based on two concepts—the six shearing layers in architectural design (Brand 1994) and the separation between Building and System in green rating schemes (Shaviv 2011)—Pushkar and Shaviv (2013) applied the six-layer shearing concept to green rating schemes for buildings. The authors (Pushkar and Shaviv 2013) suggested designing green rating systems that place greater emphasis on the Building layer, comprising the Site, Structure, and Skin sub-layers, and less emphasis on the Service layer, comprising the Services, Space Plan, and Stuff sub-layers.

Further, Pushkar (2015) applied Life Cycle Assessment (LCA) to the six shearing layers to explore the differences in their total environmental impacts for a single building module with a heavy concrete structure and envelope. It was confirmed that the environmental damage related to the Building layer (Site, Structure, and Skin) was higher (approximately 90%) than that related to the Service layers (Services, Space Plan, and Stuff) (approximately 10%) (Pushkar 2015). These results correlated with those of Menna et al. (2013), who found that the structural and nonstructural components (Building layer) were both major contributors (approximately 60–80%) to the LCA results obtained for the entire building. Thus, the Building layer, which causes much more environmental damage than the Service layer, must be designed to be environmentally correct and to have a high number of points (pts) in the green rating systems (Pushkar and Shaviv 2016).

First, the importance of the Building and Service layers in the current green rating schemes was analyzed by Pushkar and Shaviv (2016), who applied the shearing layer concept to new construction versions of the five green rating schemes: the Israeli Sustainable Standard (SI5281) (2011), BRE Environmental Assessment Method (BREEAM) (2011), Leadership in Energy and Environmental Design (LEED) (2013), Green Star (2011), and Sustainable Building Tool (SBTool) (2012). It was revealed that SI5281 focuses on the design of the long-life-expectancy Building layer; SBTool gives the same priority to both the Building and Service layers; and BREEAM, LEED, and Green Star focus on the design of the short-life-expectancy Service layer design (Pushkar and Shaviv 2016).

However, the strategies suggested by green rating systems must be evaluated in practice when analyzing green building certified projects. Such observational studies provide important feedback for further improvements to green rating systems (Wu et al. 2017). In this respect, much research has already been carried out (Fuerst 2009; Ma and Cheng 2016; Zuo et al. 2016; Wu et al. 2016; Wu et al. 2017; Pushkar and Verbitsky 2018). Mainly, LEED for New Construction and Major Renovation [NC] certified projects have been analyzed (Ma and Cheng 2016; Wu et al. 2016; Wu et al. 2017; Pushkar and Verbitsky 2018. LEED NC includes seven categories, sustainable sites (SS), water efficiency (WE), energy and atmosphere

(EA), material and resources (MR), indoor environmental quality (EQ), innovation in design (ID), and regional priority (RP). Thus, all of this research focused on several generally accepted research issues, such as project performance (i) at the certification level (Fuerst 2009), (ii) in environmental categories (Zuo et al. 2016) and category/sub-category certification (Fuerst 2009; Ma and Cheng 2016; Wu et al. 2016; Wu et al. 2017; Pushkar and Verbitsky 2018), and (iii) in cross-certification performance (the transition from a lower to higher certification level) (Wu et al. 2016; Wu et al. 2016; Pushkar and Verbitsky 2018). As a result, Silver and Gold were found to be the most popular certification levels (Ma and Cheng 2016; Wu et al. 2016; Wu et al. 2017; Pushkar and Verbitsky 2018). It was also revealed (Ma and Cheng 2016; Wu et al. 2016; Wu et al. 2017; Pushkar and Verbitsky 2018) that (i) in terms of certification performance, clustering the analyzed projects was slightly above the certification level (50 pt and 60 pt for Silver and Gold respectively), (ii) in category/sub-category certification, EA and MR were categories with the lowest performance, while SS, EQ, and ID were categories with the highest performance, and (iii) in cross-certification performance, the EA category was the main driving force moving a project through certification levels.

Such a common category-based analysis can provide some rough conclusions only about two sub-layers, Site and Services, according to performances of SS and EA categories, respectively. This is because most SS sub-categories such as SSc1 Site Selection, SSc2 Development Density & Community Connectivity, and SSc3 Brownfield Redevelopment specify building site requirements, while most EA sub-categories such as EAc2 On-Site Renewable Energy, EAc3 Enhanced Commissioning, and EAc5 Measurement & Verification specify service requirements (LEED NC 2008). Other LEED categories, WE, MR, EQ, ID, and RP, specify requirements for both Building (Site, Structure, and Skin) and Service (Services, Space Plan, and Stuff) layers together. For example, WEc1 Water Efficient Landscaping specifies requirements for the Site sub-layer (Building layer), while WEc2 Innovative Wastewater Technologies and WEc3 Water Use Reduction specify requirements for the Services and Stuff sub-layers, respectively (Service layer). Such an intertwisting of Building and Service layers must be analyzed to understand how intently and realistically certified projects handle building and system lifetime expectancies under the application of their current green rating schemes. Moreover, all of the rating schemes and certified projects analyzed mostly the NC building type, ignoring the very popular LEED for Existing Buildings: Operations and Maintenance (EB) rating scheme (Ma and Cheng 2016) and buildings certified under it (Cheng and Ma 2015).

Thus, the main goal of this research was to investigate the application of the shearing layer concept to the LEED rating schemes NC and EB and buildings certified under these schemes. To achieve this goal, the following two questions were examined:

- How do rating systems address building and system life-expectancies in their current configurations?
- How do certified projects address building and system life-expectancies in their practical applications?

RESEARCH METHODOLOGY

Data collection

Both the LEED green rating schemes and the LEED certified projects were the focus of this research. Therefore, we focused on the previous LEED version 3, which was launched in 2009 (one version before the most recent LEED version 4), because of the possibility of finding a large number of projects that were certified under this version for both new construction and existing buildings. LEED-certified projects in the US alone and only in the year 2016 were considered to maximally reduce nondemonic intrusion: "Nondemonic intrusion is defined as the impingement of chance events on an experiment in progress" (Hurlbert 1984, p.187).

Green rating schemes. The six-layers concept was applied to both the NC (2009) and EB (2009) rating schemes. The maximum available LEED pts of NC and EB rating schemes were shared among the relevant shearing sub-layers: Site, Structure, Skin, Services, Space Plan, and Stuff. The methodology of the separation procedure for the Indoor Environmental Quality (IEQ) category of NC is shown in Table 1.

The credits responsible for indoor air quality and thermal comfort, such as IEQc1 Indoor Air Delivery Monitoring, IEQc2 Increased Ventilation, IEQc3 Construction IAQ Management Plan, IEQc5 Indoor Chemical and Pollutant Source Control, IEQc6 Controllability of Systems, and IEQc7 Thermal Comfort, and their maximum available points should be relocated under the Services sub-layer due to the similar life-expectancies (from ten to twenty years) of the mechanical systems and appliances referenced in them. The rest of the indoor air quality credits, such as IEQc4.1–IEQc4.4 Low-Emitting Materials-Adhesives and Sealants, Paints and Coatings, Flooring Systems, Wood and Agrifiber Products, should be relocated under the Space plan sub-layer because these emitting materials are installed inside buildings and have the same life-expectancy (from three to ten years). The credits related to visual comfort, such as IEQc8 Daylight and Views, should be relocated under the Skin sub-layer because of their relevance to windows, which are installed in the walls.

In this way, the six-layer separation procedure was applied to (i) the NC categories,

TABLE 1. NC: separation of maximum available points to the relevant shearing sub-layers.

Credit	Credit title	Building layer			Service layer		
		Si	St	Sk	Se	Sp	Stu
IEQ	Total points 15			2	9	4	
IEQc1	Indoor Air Delivery Monitoring				1		
IEQc2	Increased Ventilation				1		
IEQc3	Construction IAQ Management Plan, Constr., Occup.				2		
IEQc4	Low-Emitting Materials, Adhes., Paints, Floor, Wood					4	
IEQc5	Indoor Chemical and Pollutant Source Control				1		
IEQc6	Controllability of Systems-Lighting, Thermal				2		
IEQc7	Thermal Comfort, Design, Verification				2		
IEQc8	Daylight and Views			2			

Si—Site; St—Structure; Sk—Skin; Se—Services; Sp—Space plan; Stu—Stuff.

including SS, WE, EA, MR, IEQ, ID, and RP, and (ii) the seven EB categories, i.e., SS, WE, EA, MR, IEQ, Innovation in Operation (IO), and RP.

Certified projects. The US projects certified in 2016 according to the NC (2008) and EB (2008) rating systems are considered. For new constructions, 920 NC-certified projects were adopted from Pushkar and Verbitsky (2018). These projects were collected by Pushkar and Verbitsky (2018) from the US Green Building Council (USGBC) project directory for new construction (http://www.usgbc.org/projects/new-construction). For existing buildings, 635 EB-certified projects from the USGBC project directory for existing building (https://www.usgbc.org/projects/existing-buildings) were revealed and collected in this study.

To increase the confidence in the statistical conclusions, the following three steps were performed for NC and EB projects: (1) the projects were divided according to Certified, Silver, Gold, and Platinum certifications, (2) the most representative certification groups were selected, and (3) states that contained five or more certified projects were selected in each of the certification groups. For each of the selected states, two sets of data were collected: (i) the USGBC scorecards of the new construction projects in the selected states (http://www.usgbc.org/projects/new-construction) and (ii) the USGBC scorecards of the existing building projects (https://www.usgbc.org/projects/existing-buildings).

Next, the following three steps were performed: (1) the information about points awarded in the NC and EB categories was documented, (2) the credit points of the NC and the EB were reallocated under the six shearing sub-layers following the six-layer point patterns revealed previously for the NC and EB rating schemes, and (3) the credit achievement degree (CAD) was calculated using the ratio adapted from Wu et al. (Wu et al 2017, p. 372):

$$CAD = \frac{\text{points of (sub)layer obtained}}{\text{total points of the (sub)layer}} \cdot 100\%$$

Data analysis

According to Picquelle and Mier (2011), some statistical terminology (e.g., a "sampling frame," a "primary sampling unit," "sub-units," and "individual sub-units") is defined below. The sampling frame is a "collection of all elements (primary sampling units) accessible for sampling in the population of interest." The primary sampling unit is an "element within the sampling frame that is sampled and is statistically independent of other sampling units within frame." The primary unit contains the "sub-units." The sub-unit contains the "individual sub-units." Measurements are performed on the individual sub-units. To statistically evaluate the relationship between primary sampling units and sub-units, the between- and within-subject variables (mixed) Analysis of Variance (ANOVA) model was used. In this context, the comparison between primary sampling units is the comparison of the between-subject variables, Factor A. The comparison between sub-units is the comparison of the within-subject variables, Factor B. The interaction between primary sampling units and sub-units is the interaction between Factor A and Factor B.

In the present study, the US is the sampling frame. Two types of buildings, NC and EB, are primary sampling units. Each building contains two sub-units: the Building layer and Service layer. The Building layer contains three individual sub-units (i.e., sub-layers): Site, Structure, and Skin. The Service layer contains three individual sub-units: Services, Space Plan, and Stuff. To statistically evaluate the relationship between two types of building (i.e., between-subject variables) and three types of individual sub-units (i.e., within-subject variables), a 2 × 3 mixed ANOVA model was used.

The comparison between the two types of building, NC and EB, is the between-subject variable. Consequently, Factor A contains two levels. The comparison among three types of individual sub-units of buildings, either Site, Structure, and Skin (sub-layers of the Building layer) or Services, Space Plan, and Skin (sub-layers of the Service layer), within either NC or EB is the within-subject variable. Consequently, Factor B contains three levels. The interaction between the two types of building (NC and EB) and either the three sub-layers of the Building layer or the three sub-layers of the Service layer is the interaction between Factor A and Factor B.

According to Hurlbert and Lombardi (2009, p. 324), a small or large P-value should be interpreted by the following paradigm: "… the P value yielded by a significance test for a difference between groups concludes one of three things: the difference between the true population means seems to be negative, it seems to be positive, or it cannot confidently be stated to be either so judgment is reserved or suspended. …. the interpretation should be a shaded one made without reference to a specified α [typically, the level of significance is $\alpha = 0.05$], and without use of terms such as 'significant' and 'non-significant'."

Statistical analysis

Significant tests. The NC projects and EB projects were divided into the following four blocks: a) Silver, Building layer; b) Silver, Service layer; c) Gold, Building layer; and d) Gold, Service layer. Before using a two-way mixed ANOVA model to evaluate the difference between NC and EB in each block, the LEED project data were log-transformed. When the ANOVA test was used, the sample size was n = 8, i.e., each primary sampling unit was a mean for each state. A two-way mixed 2x3 ANOVA included one between-subjects variable, Factor A, and one within-subjects variable, Factor B. Factor A contained two levels: NC and EB. Factor B contained three levels: Site, Structure, and Skin for the Building layer or Services, Space, and Staff for the Service layer. The *Post hoc* test for Factor A was an unpaired two-tailed t-test, and that for Factor B was a paired two-tailed t-test.

The P-values were evaluated according to three-valued logic: "it seems to be positive" (i.e., there seems to be interaction between Factor A and Factor B, or there seems to be a difference within Factor A or Factor B); "it seems to be negative" (i.e., there does not seem to be interaction between Factor A and Factor B or there does not seem to be a difference within Factor A or Factor B); or "judgment is suspended" regarding the interaction between Factor A and Factor B or the difference within Factor A or Factor B (Hurlbert and Lombardi, 2009; 2012).

RESULTS

Preliminary events: setting the projects from the most representative certifications and US states

The levels of 920 NC (adopted from Pushkar and Verbitsky 2018) and 635 EB certifications achieved in 2016 in the US (as evaluated in this study) are shown in Figure 1 and Table 2. For both certification schemes, Silver and Gold were the most representative, with 44% and 32%, respectively, for NC and with 29% and 44%, respectively, for EB.

In the present study, eight US states had statistically suitable numbers of NC and EB Silver and Gold projects in 2016: CA, FL, IL, MA, NY, TX, VA, and WA (Table 3).

FIGURE 1. Achieved levels of NC (adopted from Pushkar and Verbitsky 2018) and EB certifications in the US in 2016 (evaluated in this study).

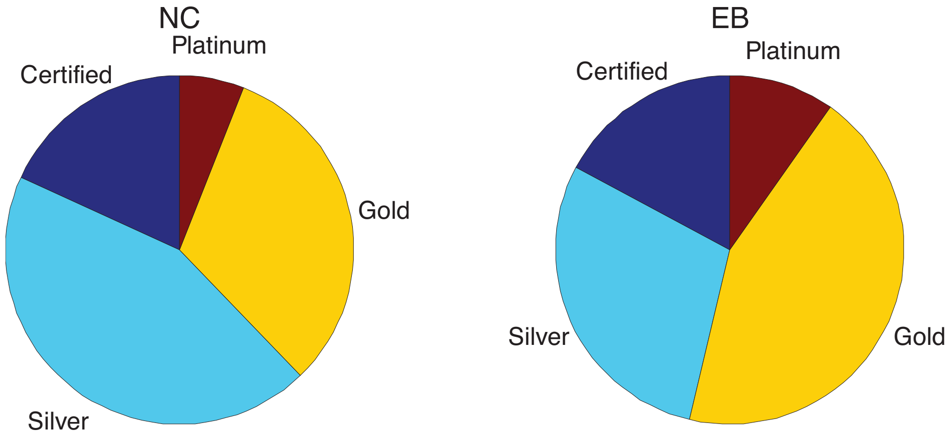


TABLE 2. NC and EB: number of projects (%) with Certified, Silver, Gold, and Platinum certifications in the US in 2016.

LEED rating scheme	Certified	Silver	Gold	Platinum
NC	167 (18%)	405 (44%)	293 (32%)	55 (6%)
EB	109 (17%)	185 (29%)	279 (44%)	62 (10%)

TABLE 3. The distribution of NC and EB Silver and Gold certified projects in US states in 2016.

	NC: sample size (n)		EB: sample size (n)	
State	Silver	Gold	Silver	Gold
California (CA)	42	58	24	81
Florida (FL)	31	11	5	14
Illinois (IL)	13	19	6	13
Massachusetts (MA)	19	14	5	15
New York (NY)	14	11	7	20
Texas (TX)	27	9	12	10
Virginia (VA)	38	11	12	12
Washington (WA)	10	11	11	9

Rating schemes

The results of the separation procedure for the six sub layers applied to the seven NC categories and the seven EB categories are shown in Figure 2 and Tables 4 and 5, respectively.

In both the NC and EB rating systems, the Service layer (timescale: from daily to monthly [Stuff sub-layer] to ten to twenty years [Services sub-layer]) is more important than the Building layer (timescale: from 20–50 years [Skin sub-layer] to eternal [Site sub-layer]) (Tables 4 and 5).

The Service layer is emphasized more in EB (71 pts) than in NC (59 pts). Thus, EB devotes almost twice the pts to the Service layer than to the Building layer. However, such an emphasis on the Service layer is not due to the Services sub-layer, which has almost the same importance

FIGURE 2. NC and EB for building shearing sub-layers (percentages) and categories (1—ID_{BL} for NC and IO_{BL} for EB; 2—ID_{SL} for NC and IO for EB; 3—RP_{BL} for both NC and EB; 4—RP_{SL} for both NC and EB).

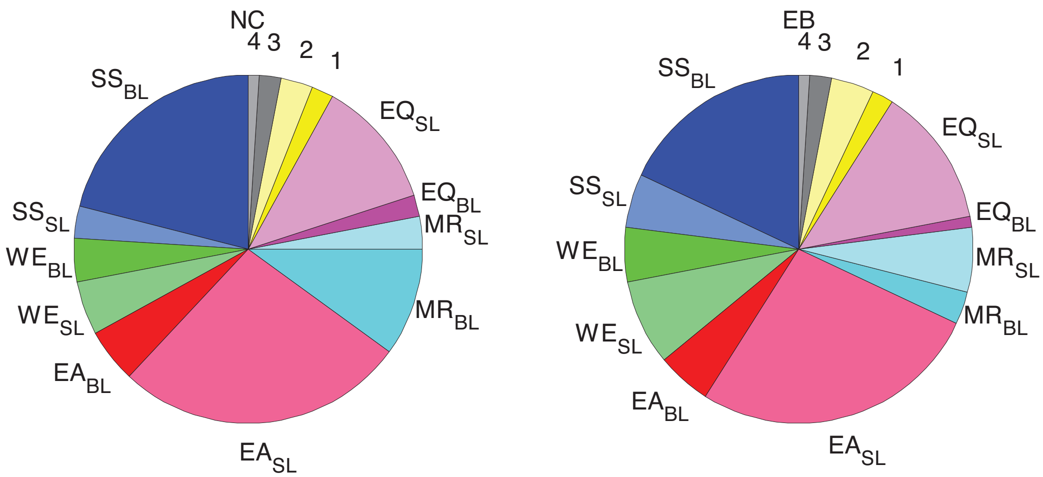


TABLE 4. NC for building shearing sub-layers (points) and categories.

Category	Total	BL	SL	Building layer			Service layer		
				Si	St	Sk	Se	Sp	Stu
SS	26	23	3	21		2	3		
WE	10	4	6	4			2		4
EA	35	5	30			5	30		
MR	14	11	3	1	2	8		1	2
IEQ	15	2	13			2	9	4	
ID	6	3	3	1	1	1	1	1	1
RP	4	3	1	1	1	1	1		
Total	110	**51**	**59**	**28**	**4**	**19**	**46**	**6**	**7**

Note: BL—Building layer; SL—Service layer; Si—Site; St—Structure; Sk—Skin; Se—Services; Sp—Space plan; Stu—Stuff.

TABLE 5. EB for building shearing sub-layers (points) and categories.

Category	Total	BL	SL	Building layer			Service layer		
				Si	St	Sk	Se	Sp	Stu
SS	26	20	6	16	1	3	6		
WE	14	5	9	5			5		4
EA	35	5	30			5	29		1
MR	10	3	7		2	1	1	1	5
IEQ	15	1	14			1	8		6
IO	6	2	4		1	1	1	1	2
RP	4	3	1	1	1	1	1		
Total	110	**39**	**71**	**22**	**5**	**12**	**50**	**2**	**19**

Note: BL—Building layers; SL—Service layers; Si—Site; St—Structure; Sk—Skin; Se—Services; Sp—Space plan; Stu—Stuff.

in both the NC and EB rating schemes, at 46 pts and 50 pts, respectively. Instead, this emphasis is due to the Stuff sub-layer, which received 19 pts in the EB scheme compared to 7 pts in the NC scheme (Table 4 vs Table 5). This is because the required purchasing of sustainable items, such as lamps, food, waste steam audit (MRc4–MRc7), green cleaning products, and materials (IEQc3.1–IEQc3.6), in the EB rating scheme was relocated under the Stuff sub-layer because they had the shortest life-expectancy (Table 5).

The Building layer is emphasized more in NC (51 pts) than in EB (39 pts). Such a difference in pts is mainly due to the MR credits, which were reallocated differently in the schemes. In NC, MRc3-MRc7 credits were Building layer-relevant pts because they involve reused, recycled, regional, rapidly renewable, and certified materials and were relocated under the Structure and Skin sub-layers, whereas in EB, most MR credits (MRc4-MRc7—sustainable stuff purchasing and waste stream audit) were located under the Stuff sub-layer, which belongs to the Service layer and not the Building layer.

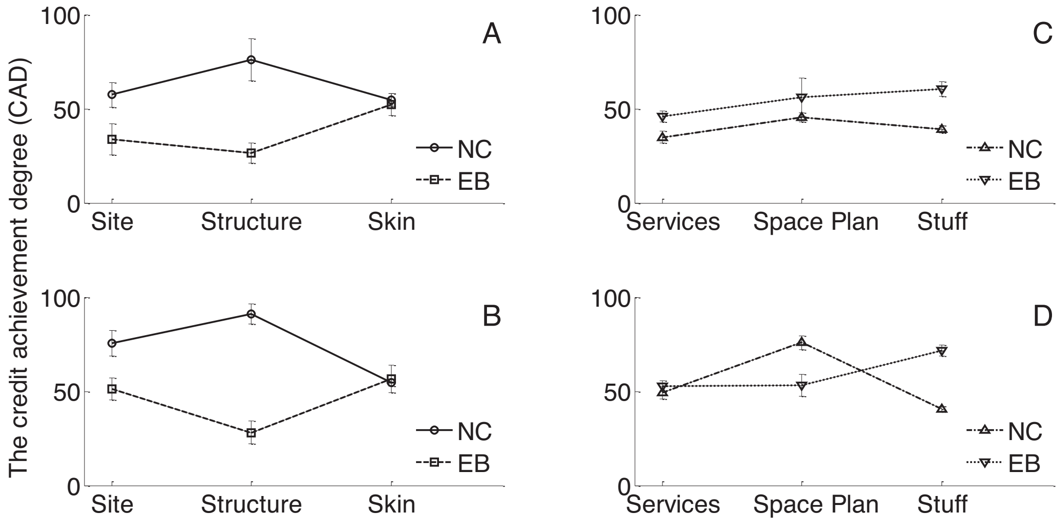
Certified projects

Graphical illustrations of the CAD means and standard deviations in four different cases, i.e., the Building layer in the Silver and Gold certifications and the Service layer in the Silver and Gold certifications, are shown in Figures 3A, 3B, 3C, and 3D, respectively. The CAD means reflect the interaction between Factor A and Factor B in each of the four cases.

Interaction between Factor A and Factor B.

As shown in Figures 3A and 3B, in the Building layer, the ordinal interactions between Factor A and Factor B seem to be positive for both Silver certification (P = 4e-07) and Gold certification (P = 5e-13). As shown in Figure 3C, in the Service layer, the ordinal interaction between Factor A and Factor B for Silver certification seems to be positive (P = 3e-03). Further, as shown in Figure 3D, in the Service layer, the disordinal interaction between Factor A and Factor B for Gold certification seems to be positive (P = 1e-16).

FIGURE 3. CADs NC and CADs EB means and standard deviations according to Building and Service layers for both Silver and Gold certification.



The ordinal interactions (Figures 3A and 3B) occurred because the interaction between CAD_{NC} (Factor A) and CAD_{St} (Factor B) is more positive than the interaction between CAD_{EB} (Factor A) and CAD_{St} (Factor B). The ordinal interaction (Figure 3C) occurred because the interaction between CAD_{EB} (Factor A) and CAD_{St} (Factor B) is more positive than the interaction between CAD_{NC} (Factor A) and CAD_{St} (Factor B). The disordinal interaction (Figure 3D) occurred because the interaction between CAD_{NC} (Factor A) and CAD_{Sp} (Factor B) is more positive than the interaction between CAD_{EB} (Factor A) and CAD_{Sp} (Factor B), whereas the interaction between CAD_{EB} (Factor A) and CAD_{St} (Factor B) is more positive than the interaction between CAD_{NC} (Factor A) and CAD_{St} (Factor B).

Between-subject variable (Factor A). As shown in Figure 3 and Table 6, for both Silver and Gold certifications, in almost all pairing comparisons, the differences between the CAD_{NC} sub-layers and CAD_{EB} sub-layers seem to be positive (1e-13 ≤ P ≤ 3e-02). The only exception is the difference between CAD_{NC} and CAD_{EB} in the Skin sub-layer, which seems to be negative for both Silver (P = 3e-01) and Gold certifications (P = 5e-01).

Within-subject variable (Factor B). In many pairing comparisons (Figure 3, Table 7), the differences between CAD sub-layers within NC and between CAD sub-layers within EB seem to be positive (2e-10 ≤ P ≤ 2e-02). The only exceptions are the differences between the CAD_{Si} and CAD_{Sk} sub-layers within NC for Silver certification, the CAD_{Si} and CAD_{St} sub-layers within EB for Silver certification, the CAD_{Si} and CAD_{Sk} sub-layers within EB for Gold certification, the CAD_{Sp} and CAD_{Stu} sub-layers within EB for Silver certification, and the CAD_{Se} and CAD_{Sp} sub-layers within EB for Gold certification, which appear to be negative, with P = 5e-01, P = 1e-01, P = 3e-01, P = 3e-01, and P = 8e-01, respectively.

Thus, Building layer performance was high in NC-certified projects and low in EB-certified projects (Figure 3). Two sub-layers were responsible for such a difference: Site (CAD_{Si} = 57.5% and CAD_{Si} = 75.4% for NC Silver and Gold, respectively, vs CAD_{Si} = 33.7 and CAD_{Si} = 51.1 for EB Silver and Gold, respectively) and Structure (CAD_{St} = 76.0% and CAD_{St} = 91.8% for NC Silver and Gold vs CAD_{St} = 26.3% and CAD_{St} = 28.0% for EB Silver and Gold), but the

TABLE 6. Between-subject variability for Building and Service layers.

	NC vs EB	P-value		NC vs EB	P-value
Building layer					
Silver	Site vs Site	**2e-05**	**Gold**	Site vs Site	**2e-06**
	Structure vs Structure	**2e-08**		Structure vs Structure	**3e-12**
	Skin vs Skin	3e-01		Skin vs Skin	5e-01
Service layer					
Silver	Services vs Services	**3e-06**	**Gold**	Services vs Services	**3e-02**
	Space Plan vs Space Plan	**3e-02**		Space Plan vs Space Plan	**2e-07**
	Stuff vs Stuff	**2e-08**		Stuff vs Stuff	**1e-13**

Note: The P-values were evaluated according to three-valued logic: bold font—seems to be positive, plain font—seems to be negative, and italic font—judgment is suspended.

TABLE 7. Within-subject variability for Building and Service layers.

Certification	Building layer	Building layer			Service layer	Service layer		
		Si	St	Sk		Se	Sp	Stu
NC, Silver	Si	X	**2e-02**	5e-01	Se	X	**4e-04**	**4e-02**
	St		X	**2e-04**	Sp		X	**2e-10**
	Sk			X	Stu			X
NC, Gold	Si	X	**3e-04**	**1e-04**	Se	X	**3e-06**	**6e-04**
	St		X	**3e-07**	Sp		X	**4e-08**
	Sk			X	Stu			X
EB, Silver	Si	X	1e-01	**3e-03**	Se	X	**2e-02**	**1e-05**
	St		X	**1e-05**	Sp		X	3e-01
	Sk			X	Stu			X
EB, Gold	Si	X	**6e-05**	3e-01	Se	X	8e-01	**1e-04**
	St		X	**2e-05**	Sp		X	**4e-04**
	Sk			X	Stu			X

Note: Si—Site; St—Structure; Sk—Skin; Se—Services; Sp—Space plan; Stu—Stuff.
The P-values were evaluated according to three-valued logic: bold font—seems to be positive, plain font—seems to be negative, and italic font—judgment is suspended.

Skin sub-layer had the same performance in both NC (CAD_{Sk} = 54.8% and CAD_{Sk} = 54.4% for Silver and Gold, respectively) and EB (CAD_{Sk} = 52.0% and CAD_{Sk} = 56.4% for Silver and Gold, respectively).

It should be noted that the Site and Structure sub-layers' high performances in NC-certified projects correlate very well with the high-performance results suggested by Wu et al. (2017) and Pushkar and Verbitsky (2018) for SS, WE, and ID categories that are mostly relevant for Site and Structure sub-layers. Wu et al. (2017) explained that this is because SS, WE, and ID are the most easily accessible categories.

The Services sub-layer performance was higher in EB-certified projects than in NC-certified projects. However, both performances are relatively low, CAD = 45.9% and CAD = 52.9% for Silver and Gold, respectively, for EB and CAD = 34.9% and CAD = 49.1% for Silver and Gold, respectively, for NC (Figure 3).

DISCUSSION

The most representative certifications: Silver and Gold

This study analyzed LEED NC and EB projects certified in 2016. It was revealed that for NC, Silver and Gold were still the most popular certifications in 2016 (44% and 32% of Silver and Gold certification projects, respectively) (Table 2). These results confirm the results presented by Wu et al. (2017) for NC projects certified in 2010–2015 (38% and 35% of Silver and Gold certification projects, respectively). Additionally, for EB, Silver and Gold were the most representative certifications, at 29% and 44%, respectively (Table 2). These results can be approximately correlated with the results presented by Cheng and Ma (2015) for EB projects certified in 2010–2015 (33% and 56% of Silver and Gold certification projects, respectively). The popularity of the Silver and Gold certification levels was explained by several reasons related to the practice of these levels, including a better cost/benefit difference, more experienced building practitioners, and reasonable time frames (Sandoval and Prakash 2016).

Rating schemes and certified projects

As was revealed, both the NC and EB rating schemes in their current configurations prefer the short-life-expectancy Service layer (59 pts and 71 pts) to the long-life-expectancy Building layer (51 pts and 31 pts) (Tables 4 and 5). These results confirm BREEAM NC (2011) and Green Star NC (2011) shearing layer separation results, which revealed that more pts were devoted to the Service layer (58 pts and 59 pts) than to the Building layer (42 pts and 41 pts) (Pushkar and Shaviv 2016).

However, the performance of NC- and EB-certified projects were different (Figure 3). NC-certified projects had high performance in the Building layer and low performance in the Service layer, whereas EB-certified projects had high performance in the Service layer and low performance in the Building layer (Figure 3). These results confirm the results demonstrated by Wu et al. (2017) and Pushkar and Verbitsky (2018) regarding LEED NC certified projects for the EA category that were mostly relevant for Services sub-layer. Wu et al. (2017) explained that EA are difficult access pts and require large investments because of EAc1 (simulations are required) and EAc3 (enhanced commission).

Thus, both the NC and EB rating schemes prefer the short-life-expectancy Service layer to the long-life-expectancy Building layer (Tables 4 and 5), while NC and EB practical applications were different: NC projects preferred to emphasize the Building layer, whereas EB preferred the Service layer (Figure 3). Such a discrepancy in the case of NC and such a similarity in the case of EB between the rating schemes and the certified projects is due to (i) the sub-layers' strategies in both rating schemes and (ii) the possibility of obtaining pts without investing large sums of money in practice. For example, the Services sub-layer (Service layer) (i) is emphasized almost equally in both rating schemes (Tables 4 and 5) and (ii) it requires large sums of money to be invested in practice for energy modeling in Optimize Energy Performance (EAc1) and Enhanced Commissioning (EAc2) credits (Wu et al. 2017). Thus, as was revealed in this study in Services sub-layer, NC and EB performed almost equally poorly (Figure 3). Another example is the Site sub-layer (Building layer). This sub-layer (i) is more emphasized by the NC scheme (Table 4) than the EB scheme (Table 5), and (ii) its application does not require high-cost investments (Wu et al. 2017) because it is composed of the SS category. Thus, as was revealed in this study in the Site sub-layer, NC performed more highly than EB (Figure 3).

CONCLUSIONS

Both LEED rating schemes (NC and EB) and in situ buildings (certified according to these schemes) were analyzed by applying the shearing layer concept. The following conclusions were drawn:

a. NC and EB rating schemes place more emphasis on the Service layer and less on the Building layer. This is in contrast to the shearing layer concept, which insists that the Building layer be valued more than the Service layer.
b. NC and EB practical applications were different. NC-certified buildings preferred the Building layer. EB-certified buildings preferred the Service layer. Consequently, the NC-certified building strategy is associated with the shearing layer concept, whereas the EB-certified building strategy does not support the shearing layer concept. Use of the shearing layer concept is associated with long life-expectancies and thereby provides green building design that is more effective in its environmental goals.

IMPLICATIONS OF THIS STUDY

This study outlines the greater environmental importance of the long-life-expectancy Building layer compared to the short-life-expectancy System layer by revealing building practices in on-site applications of LEED NC. The results of this Building-prevailing trend can help LEED experts in further versions of the rating schemes to move toward more sustainable construction.

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REFERENCES

Brand, S. 1994. *How Buildings Learn*. New York: Viking.

BREEAM (BRE Environmental Assessment Method). 2011. "BREEAM New Construction." Technical Manual. http://www.breeam.org/

Cheng, J.C.P. and Ma, L.J. 2015. "A non-linear case-based reasoning approach for retrieval of similar cases and selection of target credits in LEED projects." *Building and Environment* 93 (2): 349–361.

Duffy, F. 1990. "Measuring Building Performance." *Facilities* 8 (5): 17–20.

Fuerst, F. 2009. "Building momentum: an analysis of investment trends in LEED and Energy Star-certified properties." *Journal of Retail & Leisure Property* 8 (Nov): 285–297.
Green Star. 2011. "Green Star—Office Design v3 & Office As Built v3." http://www.gbca.org.au/green-star/rating-tools/green-star-office-v3/1710.htm.
Hurlbert, S.H. and Lombardi, C.M. 2009. "Final collapse of the Neyman-Pearson decision theoretic framework and rise of the neoFisherian." *Annales Zoologici Fennici* 46: 311–349.
Hurlbert, S.H. and Lombardi, C.M. 2012. "Lopsided reasoning on lopsided tests and multiple comparisons." *Australian & New Zealand Journal of Statistics* 54 (1): 23–42.
Hurlbert, S.H., 1984. "Pseudoreplication and the design of ecological field experiments." *Ecological Monograhs* 54: 187–211.
LEED. 2009. "LEED for Existing Buildings: Operations and Maintenance." https://www.usgbc.org/resources/leed-2009-existing-buildings-current-version
LEED. 2009. "LEED for New Construction & Major Renovations" http://www.usgbc.org/ShowFile.aspx?DocumentID=5546.
LEED. 2013. "LEED for New Construction & Major Renovations." http://www.usgbc.org/ShowFile.aspx?DocumentID=5546.
Ma, J. and Cheng, J.C.P. 2016. "Data-driven study on the achievement of LEED credits using percentage of average score and association rule analysis." *Building and Environment* 98: 121–32.
Menna, C., Asprone, D., Jalayer, F., Prota, A., and Manfredi, G. 2013. "Assessment of ecological sustainability of a building subjected to potential seismic events during its lifetime." *The International Journal of Life Cycle Assessment* 18: 504–515.
Picquelle, S.J. and Mier, K.L. 2011. "A practical guide to statistical methods for comparing means from two-stage sampling." Fisheries Research 107(1–3): 1–13, DOI 10.1016/j.fishres.2010.09.009.
Pushkar, S. 2015. "Application of Life Cycle Assessment to various building lifetime shearing layers: Site, Structure, Skin, Services, Space, and Stuff." *Journal of Green Building* 10(2): 198–214.
Pushkar, S. and Shaviv, E. 2016. "Using shearing layer concept to evaluate green systems." *Architectural Science Review* 59(2): 114–125.
Pushkar, S., and E. Shaviv. 2013. "Green Rating Systems: An Adoption of Shearing Layer Concept." In Proceeding of SB13 Oulu, edited by Finnish Association of Civil Engineers RIL VTT Technical Research Centre of Finland, 86–88. Oulu: RIL.
Pushkar, S., and Verbitsky, O. 2018). "LEED-NCv3 Silver and Gold certified projects in the US: An observational study." *Journal of green building*.
Sandoval, P. and Prakash, A. 2016. "The Gold Rush: The popularity of the Gold Tier in LEED Certification." *Environmental Policy and Governance* 26 (6): 543–555.
SBtool. 2012. "International Initiative for a Sustainable Built Environment." http://www.iisbe.org/sbtool-2012.
Shaviv, E. 2011. "Applications of simulation and CAD tools in the Israeli "Green building" standard for achieving low energy architecture." In Proceeding of Building Simulation 2011: 12th Conference of International Building Performance Simulation Association, Sydney, 14–16 November, 1258-1265.
SI5281. 2011. SI5281—Sustainable Buildings: Part 3—Requirements for Office Buildings. The Standards Institution of Israel. http://www.chamber.org.il/ images/Files/11276/5281-3.PDF.
USGBC, LEED for Existing Building Projects Directory, 2013. https://www.usgbc.org/projects/existing-buildings.
USGBC, LEED for New Construction Projects Directory, 2013 http://www.usgbc.org/projects/new-construction.
Wu, P., Mao, C., Wang, J., Song, Y., and Wang, X. 2016. "A decade review of the credits obtained by LEED v2.2 certified green building projects." *Building and Environment* 102: 167–178.
Wu, P., Songb, Y., Shoub, W., Chib, H., Chonga, H.Y., and Sutrisnaa, M. 2017. "A comprehensive analysis of the credits obtained by LEED 2009 certified green buildings." *Renewable and Sustainable Energy Reviews* 68: 370–379.
Zuo, J., Xia, B., Chen, O., Pullen, S., and Skitmore, M. 2016. "Green Building rating for office Buildings—lessons learned." *Journal of Green Building* 11(2): 131–146.