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RESEARCH ARTICLE

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Implications of sustainable features on life-cycle costs of green buildings

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Abstract

The green buildings seem unattractive to developers who prioritize fast investment returns, due to costs attributed to implementing sustainable features and consequently, only 19% of existing buildings are certified for green, globally. Furthermore, green buildings are aimed at achieving a minimum sustainability level in certification. Therefore, the current study aims to investigate the significant sustainable features and the implications of those features on green buildings' life-cycle costs. The study involved a preliminary investigation to find the significant sustainable features implemented. Subsequently, two green buildings were carefully selected, and a detailed analysis was performed. The data relating to the green building construction, operation and maintenance costs were collected and analysed using Net Present Value. The features have varying degree of contribution to sustainability in terms of the achievement of allocated points in the rating system. The certified buildings have achieved over 75% of allocated points in terms of water efficiency and sustainable sites features, while the achievement level of other features is below average level. Further, highly achieved features are more economical in terms of their less contribution to construction and maintenance costs. On the other hand, the features with lower achievement in certification, contribute significantly to construction and maintenance costs, while providing higher savings during operation. Therefore, the current study recommends, green building investors to select the most suitable features for a given construction based on their respective contributions to the life-cycle cost of green buildings.

KEYWORDS

green building, life-cycle costs, Sri Lanka, sustainable development, sustainable features

1 | INTRODUCTION

Green buildings involve structures and processes that are environmentally responsible and resource-efficient throughout a building's life cycle (United States Environmental Protection Agency [USEPA], 2017). The upfront cost commitment is a frequently cited paramount obstacle in the widespread adoption of green buildings (Hydes & Creech, 2000; Nelms, Russel, & Lence, 2005). Further, Hwang and Tan (2012) found that the high-cost premium of a green building project is the major obstacle faced in green building project management. Later, Zhou, Xu, Minshall, and Liu (2015) stated that small and medium enterprises in China are worried about the initial investment cost, return and services and maintenance cost of adopting green technologies. Similarly, Darko and Chan (2016) reviewed 36 published materials relating to green building barriers and found that the high cost of green buildings is the second most reported barrier as per the studies. Another recent survey by Dodge Data and Analytics (2016) concluded that

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concern over first costs remains the primary barrier in implementing green buildings.

In terms of the actual cost of implementing a green building, Kats (2003) found that the construction cost of a green school building ranges from 0 to 18% of its Life-Cycle Cost (LCC). Furthermore, Dwaikat and Ali (2016) indicated that the green building construction cost is higher than that of conventional buildings and falls within the range of 0–21%, depending on the type of building such as office, hospital, library, school, laboratory, house and apartment buildings. Similarly, in the context of Sri Lanka, Weerasinghe and Ramachandra (2018) concluded that the construction cost of a green industrial manufacturing building is 37% higher than that of a similar natured conventional building. Contrary to foregoing, Dwaikat and Ali (2016) stated that there is some evidence supporting that a green building costs less than a conventional building, falls up to 4%. On a slightly different note, Morris and Langdon (2007) indicated that most of the buildings require a little or no additional cost to incorporate a reasonable level of sustainable design. It could be argued that these differences in the construction cost of green buildings are partially due to the incorporation of various sustainable features that are not typically found in conventional buildings.

Green buildings incorporate various sustainable features under major focus areas such as sustainable sites (SS), management, energy and atmosphere (EA), water efficiency (WE), materials and resources (MR), indoor environmental quality (IEQ) and health. (Fowler & Rauch, 2006; Nguyen & Altan, 2011; Say & Wood, 2008). A marketing study, by Langdon (2007) analysed a total of 83 LEED-certified buildings and 138 non-LEED certified buildings and the implication of sustainable features on construction cost was assessed using a four-point qualitative scale such as Minimal (M), Low (L), Significant (S) and Minimal to Significant (M to S). The authors found that the EA features require a high cost, a high degree of focus and can be challenging for many green building projects among other sustainable features considered. On a detailed view, other studies reported that the acquisition of green technologies such as photovoltaic systems, redundant mechanical systems and geothermal strategies incur expensive cost additions for green buildings (Mapp, Nobe, & Dunbar, 2011; Rehm & Ade, 2013). In another point of view, Zhang, Platten, and Shen (2011) explained that passive design strategies; walls insulation, low-E window, and solar heating appliance involve relatively lower additional cost, whereas active design strategies; ground source heat pumps, radiant flooring and electric and radiant heating system are very expensive for the initial installation.

A notable observation of the past studies is that the researchers were unable to show the implications of these sustainable features on the LCC, particularly on the operational and maintenance cost of green buildings. Further, the findings on the implication of sustainable features on construction costs of green buildings were limited to a few countries, few building types and mostly to energy efficiency technologies. However, one would expect that the increased construction cost due to the implementation of sustainable features should offset saving on operation and maintenance (O&M) costs. Therefore, an investigation into the assessment of green implications on LCC is pertinent to promote green building applications and achieve sustainability. Moreover, given the initial cost barrier of green buildings, Darko and Chan (2016) recommended the research works on the life-cycle approach for assessing the cost and impact of green buildings and the analysis of the life-cycle performance and benefits of green buildings to improve the investors' awareness on green building's performances and benefits over conventional buildings. In this context, the current study identifies the significant sustainable features and the implications of those features on green buildings' LCC. It is expected that the outcome of this study would enable potential green investors to make informed decisions with sound knowledge of sustainable features and its cost implications. This would further enhance the sustainability performances of buildings and promote sustainable development.

2 | LITERATURE REVIEW

2.1 | Sustainable features of green buildings

Globally, several green building evaluation tools focus on different areas of sustainable development and are designed for use in diverse types of projects. By March 2010, there were 382 registered building software tools for evaluating energy efficiency, renewable energy and buildings' sustainability (Nguyen & Altan, 2011). Nowadays, most of the countries have established a body of environmental certification and developed national assessment systems for sustainability (Smith, Fischlein, Suh, & Huelman, 2006). However, only a few systems are widely acknowledged and set a recognizable standard for sustainable development. The first environmental certification system, BREEAM was introduced in 1990 in the United Kingdom (UK), and subsequently, in 1998, the LEED Green Building Rating System was established based on the BREEAM system. In 1996, the Hong Kong Building Environmental Assessment Method (HK-BEAM) was initiated, while Japan developed the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) in 2001. The Green Star was introduced by Australia in 2003 and currently, New Zealand follows the same rating system. Similarly, in 2005, the Green Building Initiative (GBI) launched Green Globes by adapting the Canadian version of BREEAM and distributing it in the United States (US) market. In the Sri Lankan context, Green Building Council of Sri Lanka (GBCSL) has developed GREENSL in 2010 following LEED. These rating systems can be applied to any building type such as office, industrial, retail, school, homes, residential, healthcare, educational facilities and institutional buildings. Further, these rating systems apply to new construction as well as existing buildings. The key sustainable features that are crucial for a green building can be categorized according to major categories of features included in different green building rating systems. Accordingly, Fowler and Rauch (2006); Nguyen and Altan (2011); Say and Wood (2008) analysed the available green rating systems and identified that SS, WE, EA, MR and IEQ areas are common sustainable features applicable to above-mentioned building types while there are few features which are specific to certain rating systems only. The current study considers these common features in the assessment of their effects on the LCC of green buildings.

2.2 | The implications of sustainable features on construction costs

Previous studies have revealed that the high construction cost of green buildings is attributed to the incorporation of sustainable features which eventually hinder the widespread adoption of green buildings (Hydes & Creech, 2000; Nelms et al., 2005). This section reviews the implication of sustainable features on construction cost giving due consideration to the above-identified sustainable features.

The study of Akadiri, Chinyio, and Olomolaiye (2012) recommended that the use of cost-saving construction techniques such as the use of masonry stone instead of reinforced concrete for building foundation would minimise the initial construction cost. These authors further added that the design should optimize the use of locally available materials, which will reduce transport costs and import duties. Additionally, the use of renewable materials minimises replacement costs, whereas, using recycled materials can significantly reduce overall project cost. For example, using products with high recycled content, such as recycled asphalt or cement replacement in concrete products can save project costs by at least 3% (Innes, 2004). On a different note, based on the analysis of the actual cost of 17 green buildings, Rehm and Ade (2013) concluded that green buildings are expensive due to their provision of specific sustainable features such as green materials, high-performance cladding systems, rainwater harvesting and energy-efficient mechanical equipment.

Another study, Langdon (2007) conducted a marketing study a total of 83 LEED-certified buildings and 138 non-LEED certified buildings including academic, laboratory, library, community centres and ambulatory care facilities in the same location and discussed the feasibility of each LEED point and overall likely cost effect for initial construction cost. The study investigated the implications of sustainable features on construction cost using a four-point scale such as,

- M—No cost or Minimal: No construction cost or soft cost only (less than $1.00/sq. ft. of building area)
- L—Low: $1.00 to $3.00/sq. ft. of building area
- S—Significant: $3.00 to $8.00/sq. ft. of building area
- M to S—Minimal to Significant: less than $1.00 to $8.00/sq. ft. of building area

Table 1 presents a summary of the study.

As observed from Table 1, the implication of 49 sustainable features on construction cost was indicated as per the above four-point qualitative scale. Accordingly, 12, 20 and 31% of sustainable features have indicated a low, significant and minimal cost, respectively, where 37% of features are in minimal to significant category that indicates the implication of sustainable features on the construction cost of green buildings could vary greatly. Many SS features can be readily achievable at a little cost at the construction stage and have a low construction cost implication, whereas the features in IEQ are readily achievable with low costs. Similarly, the sustainable features: ID and RP are either achieved with a minimal cost implication or readily achievable with other sustainable features. On the other hand, the features in WE have a low construction cost implication, except when the project involves innovative wastewater technologies like sewage treatment plant (STP) with high-end technologies. However, features of EA can be challenging for many projects, therefore they require a high degree of focus and high construction cost. The construction cost associated with almost all the features of MR could be ranged from minimal to significant considering the compliance or other physical conditions.

The above implications for construction costs are possibly due to several reasons. For example, Matthiessen and Morris (2004) highlighted that the cost of the green is influenced by demographic location: rural or urban, bidding climate and culture, local and regional design stages including codes and initiatives, intent and values of the project, climate and timing of implementation, size of building and point synergies. Similarly, Zhang et al. (2011) found implications of innovative green design features, complicated research and development process and the willingness of building owners to commit time and cooperation could imply the cost of the building.

In the study of Kats (2003), the average cost premium of 33 green buildings across the US was analysed and showed that increased architectural and engineering design time, modelling costs and time required to integrate green features into projects increase the cost premium. Moreover, Fullbrook and Woods (2009), Kats et al. (2008) and Packard foundation (2002) have found that the cost of certification depends on the level of sustainability. Similarly, Kim, Greene and Kim, Greene, and Kim (2014) found that the upgrades to adhere to green building codes directly affect the bid amount presented to the client and construction schedule. Due to increased project duration, the longer the contractor is on a project site, the project will require greater capital expenditure.

Despite these identified the implication of sustainable features to the construction cost of green projects, the previous authors have failed to identify the implication of sustainable features on the LCC of green buildings. Even though, the study of Langdon (2007) has analysed the cost implication qualitatively on a four-point scale where the scale is inadequate to indicate the significance of most of the sustainable features. Moreover, the reasons for varying cost contributions could be due to the physical, performance and functional characteristics of the green buildings. Therefore, when analysing the cost of the green buildings, due consideration is to be given to these factors. Therefore, the current research investigates the significance of sustainable features and the implications of each feature on the LCC of green buildings.

3 | RESEARCH METHODS

The current study was primarily approached quantitatively where a preliminary document analysis was carried out referring to the Green Building Directory of United States Green Building Council (USGBC)

TABLE 1 The implications of sustainable features on construction cost

Level of implication	Sustainable features		Code	No. of features
No cost or minimal (M)	SS	Alternative transportation—Public transportation access	SS4	15 out of 49 features (31%)
		Alternative transportation—Bicycle storage and changing rooms	SS5	
		Alternative transportation—Low-emitting and fuel-efficient vehicles	SS6	
		Alternative transportation—Parking capacity	SS7	
		Light pollution reduction	SS14	
	MR	Regional materials	MR6	
	IEQ	Outdoor air delivery monitoring	IEQ1	
		Construction IAQ management plan—Before occupancy	IEQ4	
		Low-emitting materials—Adhesives and sealants	IEQ5	
		Low-emitting materials—Paints and coatings	IEQ6	
		Low-emitting materials—Flooring systems	IEQ7	
		Thermal comfort—Design	IEQ12	
	Innovation in design (ID)	Innovation in design	ID1	
		LEED® accredited professional	ID2	
	Regional priority (RP)	Regional priority	RP	
Low (L)	WE	Water use reduction	WE3	6 out of 49 features (12%)
	EA	Enhanced refrigerant management	EA4	
	IEQ	Increased ventilation	IEQ2	
		Indoor chemical and pollutant source control	IEQ9	
		Controllability of systems—Thermal comfort	IEQ11	
		Thermal comfort—Verification	IEQ13	
Significant (S)	SS	Stormwater design—Quality control	SS11	10 out of 49 features (20%)
		Development density & community connectivity	SS2	
		Brownfield redevelopment	SS3	
		Heat island effect—Roof	SS13	
	WE	Innovative wastewater technologies	WE2	
	EA	Optimize energy performance	EA1	
		Onsite renewable energy	EA2	
		Enhanced commissioning	EA3	
		Measurement and verification	EA5	
		Green power	EA6	
Minimal to significant (M – S)	SS	Site selection	SS1	18 out of 49 features (37%)
		Site development—Protect or restore habitat	SS8	
		Site development—Maximize open space	SS9	
		Stormwater design—Quantity control	SS10	
		Heat island effect non-roof	SS12	
	WE	Water-efficient landscaping	WE1	
	MR	Building reuse	MR1&2	
		Construction waste management	MR3	
		Materials reuse	MR4	
		Recycled content	MR5	
		Rapidly renewable materials	MR7	
		Certified wood	MR8	

TABLE 1 (Continued)

Level of implication	Sustainable features		Code	No. of features
	EA	Construction IAQ management plan—During construction	IEQ3	
		Low-emitting materials—Composite wood and agrifiber products	IEQ8	
		Controllability of systems—Lighting	IEQ10	
		Daylight and views—Daylight	IEQ14	
		Daylight and views—Views	IEQ15	

Note: Source: Adapted from Langdon (2007).
Abbreviations: EA, energy and atmosphere; IEQ, indoor environmental quality; MR, materials and resources; SS, sustainable sites; WE, water efficiency.

to identify the available green space types in Sri Lanka and the significance of sustainable features of green buildings. According to data published in the Directory, altogether 38 buildings are certified with LEED to date. Among, eight (08) green industrial manufacturing spaces, which were certified under LEED BD + C: New Construction & Major Renovations (V.3–2009) rating system, were screened and compared the points achieved with points allocated to identify the significant sustainable features. The eight (08) industrial manufacturing spaces include Garment (04), Printing and Packaging (03) and Cleaning Products (01) buildings. Subsequently, costs and savings of two (02) green industrial manufacturing buildings with similar functional characteristics such as location, climate condition, tenure, that is, management style and quality of the selected green building were compared to identify the implications of significant sustainable features on green buildings' LCCs. Also, physical and performance characteristics such as the year of construction, number of floors, shape, Net Internal Area (NIA), designed life-cycle, building height, number of occupants, type of function, type of building structure, roof structure, roof material, orientation and glazing orientation were matched among two cases. However, it was not matched other factors like end-user behaviours and glazing type.

The construction cost data were collected according to the standard cost categories of Royal Institution of Chartered Surveyors (RICS) New Rules of Measurement (NRM), whereas annualised and periodic O&M costs data were collected according to a cost template developed using costs classifications introduced by BS ISO 15686-5:2008 standard, NRM and Building Cost Information Service (BCIS). Afterward, the cost contributions and the cost savings of the sustainable features of the selected buildings were analysed using Net Present Value (NPV) analysis. All the costs were discounted for the base year. The analysis was carried out for 50 years based on the discount rate (4.26%) obtained from the Central Bank of Sri Lanka.

4 | ANALYSIS AND FINDINGS

4.1 | Preliminary analysis and findings

As per the data published in the USGBC database, LEED encompasses more than 50,000 LEED building projects over 150 countries and territories, of which, only 38 LEED building projects are in Sri Lanka to date (USGBC, 2017). Among, a majority of newly constructed buildings were certified as per LEED BD + C: NC & Major Renovations (V.3–2009) rating system. The analysis of LEED-certified green buildings profile in Sri Lanka indicates that the green industrial manufacturing buildings under the LEED BD + C: NC (v3–2009)*** rating system represents the largest sample (08 out of 38 buildings) of green space types. The points achieved to each major sustainability criteria compared to points allocated of the above sample was analysed and the average points achievement was considered to identify the significance of sustainable features in the Sri Lankan green buildings. The sustainable features which achieved higher than 50% of its allocated points were considered as significant features. Table 2 presents the level of achievement of sustainability in terms of each feature.

As observed in Table 2, there are 49 sustainable features under seven major principle sustainable features. Considering the percentage of average achievement level comparing to the given points, 32 out of 49 features were found as significant for the green-certified buildings, whereas 17 out of 49 features are less significant. The reasons for the lack of achievement of points could be due to the implications of the sustainable features on construction costs as identified in the literature review of this study. Similarly, Mapp et al. (2011) and Rehm and Ade (2013) showed that the energy efficiency feature contributes significantly to the cost of green buildings. According to Langdon (2007), those features indicate both minimal or low and significant contribution to construction cost. Further, in terms of sustainable features: SS3, SS10, EA2, EA6, MR1, MR2, MR4, MR7, MR8, IEQ8 and IEQ10, the costs of implementing these features are significant (Langdon, 2007). This could be the reason for the lower-level achievement of those features. However, other features such as SS14, IEQ1, IEQ4, IEQ9, IEQ11, IEQ12 and IEQ13 having lower achievement levels show a minimal or low contribution to total cost (Langdon, 2007). On the other hand, features with higher achievement levels such as SS11, SS13 and EA5 also show a significant contribution to construction costs (Langdon, 2007). However, the findings of Langdon (2007) study has limitations, the cost implications were assessed on a four-point qualitative scale, limited to implications on construction costs only, and sample considered included different types of buildings together.

Figure 1 illustrates the sustainable features implemented, and points achieved for those features in the green-certified 08 industrial manufacturing buildings.

TABLE 2 Significance of sustainable features in terms of points allocation

Sustainable features			Point allocation	Average points achievement (out of 08 approved green industrial buildings)	
				Points	Percentage (%)
EA	Optimize energy performance	EA1	19	9.500	50%
	Onsite renewable energy	EA2	7	0.875	13%
	Measurement and verification	EA5	3	2.625	88%
	Green power	EA3	2	1.000	50%
	Enhanced commissioning	EA4	2	1.250	63%
	Enhanced refrigerant management	EA6	2	0.000	0%
	Sub Total		**35**	**15.250**	**44%**
SS	Alternative transportation—Public transportation access	SS4	6	5.250	88%
	Development density & community connectivity	SS2	5	3.125	63%
	Alternative transportation—Low–emitting and fuel-efficient vehicles	SS6	3	3.000	100%
	Alternative transportation—Parking capacity	SS7	2	2.000	100%
	Site selection	SS1	1	0.750	75%
	Brownfield redevelopment	SS3	1	0.000	0%
	Alternative transportation—Bicycle storage and changing rooms	SS5	1	1.000	100%
	Site development—Protect or restore habitat	SS8	1	0.500	50%
	Site development—Maximize open space	SS9	1	0.750	75%
	Stormwater design—Quantity control	SS10	1	0.375	38%
	Stormwater design—Quality control	SS11	1	1.000	100%
	Heat island effect non-roof	SS12	1	1.000	100%
	Heat island effect—Roof	SS13	1	0.875	88%
	Light pollution reduction	SS14	1	0.250	25%
	Sub total		**26**	**19.875**	**76%**
IEQ	Outdoor air delivery monitoring	IEQ1	1	0.125	13%
	Increased ventilation	IEQ2	1	0.625	63%
	Construction IAQ management plan—During construction	IEQ3	1	0.750	75%
	Construction IAQ management plan—Before occupancy	IEQ4	1	0.375	38%
	Low-emitting materials—Adhesives and sealants	IEQ5	1	0.875	88%
	Low-emitting materials—Paints and coatings	IEQ6	1	1.000	100%
	Low-emitting materials—Flooring systems	IEQ7	1	0.500	50%
	Low-emitting materials—Composite wood and agrifiber products	IEQ8	1	0.000	0%
	Indoor chemical and pollutant source control	IEQ9	1	0.000	0%
	Controllability of systems—Lighting	IEQ10	1	0.375	38%
	Controllability of systems—Thermal comfort	IEQ11	1	0.000	0%
	Thermal comfort—Design	IEQ12	1	0.250	25%
	Thermal comfort—Verification	IEQ13	1	0.250	25%
	Daylight and views—Daylight	IEQ14	1	0.875	88%
	Daylight and views—Views	IEQ15	1	0.875	88%
	Sub total		**15**	**6.875**	**46%**
MR	Building reuse—Existing elements	MR1	3	0.750	25%
	Construction waste management	MR3	2	2.000	100%
	Materials reuse	MR4	2	0.125	6%
	Recycled content	MR5	2	1.000	50%
	Regional materials	MR6	2	2.000	100%
	Building reuse—Interior non-structural elements	MR2	1	0.000	0%

TABLE 2 (Continued)

Sustainable features			Point allocation	Average points achievement (out of 08 approved green industrial buildings) Points	Percentage (%)
	Rapidly renewable materials	MR7	1	0.000	0%
	Certified wood	MR8	1	0.000	0%
	Sub total		**14**	**5.875**	**42%**
WE	Water-efficient landscaping	WE1	4	4.000	100%
	Water use reduction	WE3	4	4.000	100%
	Innovative wastewater technologies	WE2	2	2.000	100%
	Sub total		**10**	**9.750**	**100%**
ID	LEED® accredited professional	ID2	1	1.000	100%
	Innovation in design	ID1	5	3.125	63%
	Sub total	**6**	**4.125**	**69%**	
RP	Regional priority	RP	4	3.000	75%
	Sub total		**4**	**3.000**	**75%**

Abbreviations: EA, energy and atmosphere; IEQ, indoor environmental quality; MR, materials and resources; SS, sustainable sites; WE, water efficiency.

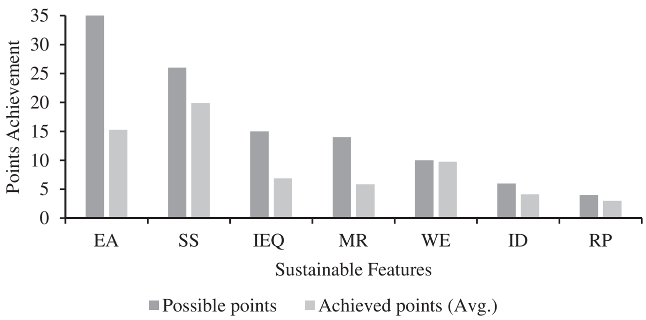

FIGURE 1 Level of achievement of sustainable features of green buildings

As shown in Figure 1, EA has the highest possible points, the green-certified buildings have achieved 15 points out of 35 allocated, while in terms of SS feature, the second-highest points assigned, the certified buildings have achieved 20 points (out of 26). The features, MR and IEQ have achieved about 50% level (7 out of 14 points) and 33% (5 points out of 15), respectively.

Considering WE, all green-certified buildings have achieved the maximum allocated of points of 10 whereas, ID and RP each have achieved 4 points. When the points allocations are considered, the sustainable features: SS, EA, WE, IEQ and MR are identified as the most significant, whereas, ID and RP are less significant. Overall, the sustainable features: WE have achieved 100% and SS achieved over 75% of the given points. However, the achievement levels of EA, IEQ and MR have been between 40 and 50%. This lower level achievement could be partially due to the implementation cost effects of those features. Similarly, the study of Langdon (2007) found that many features in SS, WE and IEQ are readily achievable with low costs, whereas EA features can be challenging for many projects and the construction cost associated with almost all the features of MR could range from minimal to significant.

Having analysed the level of achievement of sustainability in terms of points achieved, 2 out of 8 industrial manufacturing buildings were selected to study in detail the reasons for the level of achievement and cost implications of sustainable features implemented.

4.2 | Profile of cases

The two green buildings were carefully selected by considering the similarity of important functional, physical and performance features and Table 3 presents the profile of the two selected buildings. As seen from Table 3, the year of commencement, the shape of the building and designed life-cycle were made identical for the selected buildings. However, in terms of the size of buildings, the selected two buildings are slightly different from each other. Further, in terms of structure, both buildings consist of a low pitched roof on a steel frame structure. The number of occupants in the organizations is closely related, but the end-user behaviours were not to be matched, though it is a highly influential factor on the cost of buildings (United States General Services Administration [USGSA], 2011). Considering the orientation of the selected buildings, the rectangular floor plans were elongated on an east–west direction and a larger portion of the glazing was included in the south-facing wall.

4.3 | LCC of green industrial manufacturing buildings

Initially, the NPV of the two (02) buildings were calculated considering the analysis period of 50 years and the discount rate of 4.26%. The costs data related to construction, annualised O&M and end life were collected by refereeing to construction and O&M expenditure budget records, according to standard cost categories classified by RICS NRM 1 and Building Maintenance Costs Information Service (BMCIS). According to NRM 1, the construction cost of buildings consists of facilitating work, building work, main contractor's preliminaries, main contractor's overheads and profit, project/design team fees, other development/project costs, client's contingencies and taxes. Except for the cost of building works and facilitating works, the rest of the cost items were labelled as "Other costs." The "Cost of LEED certification" includes LEED registration fee, documentation costs, LEED consultancy and hiring LEED Accredited Professionals.

Operational costs include insurance, utility, administrative costs and taxes, whereas, the costs of fabric and decorations, building services, cleaning and external works and repairs and replacement of minor systems/components contribute to maintenance costs of the selected buildings. 71 O&M elements were identified according to the BMCIS classification. However, the analysis considered only 59 out of 71 cost data due to its suitability and availability in the Sri Lankan context. The end LCC of buildings consists of disposal inspection, disposal and demolition, reinstatement to meet contractual requirements, taxes and other costs. All the costs were discounted to the year 2018 and normalized considering cost per m2 of NIA. Table 3 illustrates a detailed analysis of the LCC of green buildings.

As shown in Table 4, among the major LCC elements, the construction cost of green industrial manufacturing buildings consumes 16% of the LCC of the selected buildings. The O&M cost is responsible for 70 and 14% of total LCC, respectively, while the contribution of end life costs is very marginal, 0.04%. The major contributor to the construction cost is building work, which contributes around 75%. Around 10% of construction cost is incurred in achieving LEED green certification. A considerable contribution to the operation cost is from the utilities (41%), while services, fabric and decorations contribute up to 84% of the maintenance cost.

Following the above, the costs related to implementing, operating and maintaining specific sustainable features incorporated in the selected buildings were extracted from the sub costs elements and analysed the implication of sustainable features on major LCC

TABLE 3 Profile of green industrial manufacturing buildings

Building	GB 1	GB 2
Year of construction	2013	2013
No. of floors	1	1
Shape	Rectangular	Rectangular
NIA (m2)	3,809	3,567
Life-cycle	50	50
Building height(m)	3.8	4
No. of occupants	1,400	1,310
Type of function	Garment	Garment
Type of structure	Steel	Steel
Roof structure	Low pitched roof	Low pitched roof
Roof material	Metal roof	Metal roof
Orientation	East–west	East–west
Glazing orientation	South facing	South facing
Location	Western province	Western province
Climate condition	Tropical	Tropical

Abbreviation: NIA, Net Internal Area.

TABLE 4 LCC of green industrial manufacturing buildings

LCC elements		Cost per unit area (LKR/m^2)					
Main	Sub	GB 1	%	GB 2	%	Average GB	%
Construction		80,307	16	81,082	17	80,695	16
	Building works	59,263	74	60,869	75	60,066	74
	LEED certification	9,301	12	7,009	9	8,155	10
	Other costs	6,953	9	8,410	10	7,682	10
	Facilitating works	4,790	6	4,794	6	4,792	6
Operation		347,042	70	333,689	69	340,366	70
	Utilities	150,675	43	131,087	39	140,881	41
	Administrative cost	105,951	31	117,131	35	111,541	33
	Other costs (insurance and taxes)	90,416	26	85,471	26	87,944	26
Maintenance		69,408	14	67,278	14	68,343	14
	Fabric & decoration	33,108	48	26,935	40	30,022	44
	Services	25,833	37	29,296	44	27,565	40
	Repairs and replacement	4,534	7	4,038	6	5,849	9
	Cleaning & external works	5,482	8	7,012	10	4,908	7
End life-cycle		181	0.04	163	0.03	172	0.04
NPV (LCC)		496,938	100	482,212	100	489,575	100

Abbreviations: LCC, Life-Cycle Cost; NPV, Net Present Value.

elements: construction, O&M. The next section presents an analysis of the implications of sustainable features.

4.4 | The implications of sustainable features on construction cost

The total construction cost of green buildings may vary due to the cost of implementing sustainable features as part of building works. Thus, this section analyses the cost contributions of each sustainable feature to the total construction costs. Table 5 summarises the total construction cost of two green buildings and the contribution of sustainable features to the construction cost.

According to Table 5, the total construction cost of green building is composed of the cost of building, integration of sustainable features and the administration cost for achieving LEED certification. The cost of LEED certification is 10% of total construction cost, while implementing sustainable features is responsible for 18% of total construction cost, contributes to higher construction cost. This 18% is shared by features of SS, WE, EA, IEQ and MR. Of them, EA and IEQ receive the highest position with a contribution of 7 and 6% to total construction cost, respectively. In terms of EA and IEQ, the sub-features such as EA1, EA3, EA5, IEQ3, IEQ14 and IEQ15 contribute significantly to the total construction cost. However, Langdon (2007) showed that IEQ related sustainable features have low-cost implications compared to other sustainable features.

Other sustainability features: MR, SS and WE contribute 3, 2 and 1%, respectively, for the construction cost of green buildings. In terms of features with these main sustainability focuses, MR1, MR3, MR4, MR5, SS6, SS8, SS10, SS12 and WE1 are responsible for these contributions.

4.5 | The implications of sustainable features on maintenance cost

The implication of sustainable features on operation cost is rather minimal, therefore the current study only considers the implications of sustainable features on the maintenance cost of the selected two green buildings. The maintenance cost of green buildings is divided into two major components like the maintenance cost of sustainable features and other maintenance costs. Table 6 summarises the cost implications of each principal sustainable feature to the total maintenance cost.

According to Tables 6, 72% of the total maintenance cost is dedicated to maintaining sustainable features. Among, IEQ involves the highest maintenance cost of 31%, while another 26% is due to maintaining EA features. The sustainability features: MR, SS and WE are responsible for the remaining 15% of the total maintenance cost. Both IEQ and EA features have the top priority in terms of maintenance costs contribution, involve higher maintenance costs.

Although the selected buildings have achieved less points of the allocated points in terms of EA and IEQ, the implemented sustainable features under these categories contribute significantly to construction and maintenance costs and in return responsible for the substantial saving of electricity during the operation stage. However, other main sustainable features: SS, WE and MR involve fewer costs both in terms of construction and running cost. On a contrary view of this, Langdon (2007) indicated that features which have a minimal or low contribution to total cost have lower achievement level and vice versa. Therefore, the study recommends that green building investors select the most suitable sustainable features, considering its implications to LCC which ultimately contribute to reducing the LCC of green buildings.

4.6 | The implications of sustainable features on operational savings

The green buildings are said to have fewer cost implications during the operational phase, compared to conventional buildings of similar nature due to the operational savings contributed by the integrated sustainable features. In the current study, the implications of sustainable features on operational savings were observed in terms of electricity, water, waste disposal and carbon emission. Monthly electricity

TABLE 5 Implication of sustainable features on construction cost

Cost element	Contribution to construction cost (LKR/m2) GB1	%	GB2	%	Avg. %	Sustainable features incorporated
Total construction cost	**80,307**	**100**	**81,082**	**100**	**100**	
Other costs	58,960	73	58,667	72	72	
Cost for sustainable features	12,046	15	15,406	19	18	
EA	4,818	6	5,676	7	7	EA1, EA3, EA5
IEQ	4,092	5	4,818	6	6	IEQ1, IEQ3, IEQ4, IEQ6, IEQ14, IEQ15
MR	1,606	2	2,432	3	3	MR1, MR3, MR4, MR5, MR6
SS	951	1	1,278	2	1	SS4, SS5, SS6, SS7, SS8, SS10, SS12
WE	579	1	1,201	1	1	WE1, WE2, WE3
LEED certification	9,301	12	7,009	9	10	

Abbreviations: EA, energy and atmosphere; IEQ, indoor environmental quality; MR, materials and resources; SS, sustainable sites; WE, water efficiency.

TABLE 6 Implication of sustainable features on maintenance costs

	Contribution to maintenance cost per unit area (LKR/m^2)					
Cost	GB1	%	GB2	%	Avg. %	Respective maintenance cost elements
Total maintenance cost	**69,408**	**100**	**67,278**	**100**	**100**	
Maintenance of sustainable features	46,424	67	51,126	76	72	
IEQ	21,847	29	20,459	32	31	Fabric and decoration Services: Heating and ventilation, mechanical services, electric power and lighting
EA	18,585	25	17,404	28	26	Services: Heating and ventilation, mechanical services, electric power and lighting
MR	6,124	6	4,280	9	8	Fabric and decoration Cleaning
SS	4,109	6	3,848	6	6	Cleaning and external works
WE	461	1	432	1	1	Services: Plumbing and drainage
Other building maintenance	22,985	33	16,152	24	28	

Abbreviations: EA, energy and atmosphere; IEQ, indoor environmental quality; MR, materials and resources; SS, sustainable sites; WE, water efficiency.

consumption per production (total kWh divided by the number of production units) was extracted for 12 months. Then, the average electricity saving of the two green buildings was compared with a benchmark value determined by the selected organisations. Accordingly, green buildings are responsible for a 26% reduction in electricity consumption. Similarly, the water consumption of green buildings was compared with the benchmark levels set by the organisations. Accordingly, a 31% reduction in water consumption was achieved in green buildings. This reduction is attributed to the WE feature implemented in the selected green buildings. The electricity and water consumption of green buildings together contribute to a 35% reduction in the total operation cost of green buildings.

In terms of end life cost, it was estimated that an average of 99% of the total waste from the selected green buildings will be diverted from landfill and thereby contribute to environmental sustainability and further reduce the end life costs. According to the building measurements records maintained in the selected green buildings, it is revealed that the selected green buildings contribute to a 27% reduction of carbon footprint, whereas in the global context, CO2 emission reduction equals to 36% (USGSA, 2011).

5 | DISCUSSION OF RESULTS

Preliminary analysis of eight (08) green industrial manufacturing buildings certified under the LEED BD + C: NC (v3–2009) shows that the sustainable features: SS and WE are highly integrated in the green buildings and shows a 75% of achievement of allocated points, while other features EA, IEQ and MR have achieved between 40 and 50%. Further, when these features considered for its implications on construction costs and maintenance cost, SS, WE and MR are much more economical than other features: EA and IEQ which have lower achievement levels and contribute significantly to construction and maintenance costs.

As the detailed analysis confirmed EA and IEQ contribute 7 and 6% to total construction cost, and 26 and 31% to total maintenance cost, respectively. The contribution of other features is less than that. The sub features of EA and IEQ such as optimize energy performance, green power, measurement and verification, construction IAQ management plan—during construction and daylight and views have 50% or more than 50% individual achievement levels are responsible for the above contributions of construction and maintenance costs. The sub features of MR such as materials reuse, building reuse—existing elements, recycled content and construction waste management have achieved 6, 25, 50 and 100%, respectively. However, having various achievement levels, these MR features contribute to construction cost by 3% and maintenance costs by 9%. The sub features of WE and SS such as water-efficient landscaping, alternative transportation—low–emitting and fuel-efficient vehicles, and heat island effect non-roof have 100% achievement level, while site development—protect or restore habitat and stormwater design—quantity control have integrated 50 and 38%, respectively. These WE and SS features contribute to 1–2% of total construction cost and 1–6% of maintenance costs.

In terms of operational savings, it is seen that electricity and water consumption of green buildings together contribute to 35% of the total operation cost of green buildings, whereas, in terms of end life costs, an average of 99% of the total waste from a green building divert from landfill and reduce 27% of the carbon footprint. The sustainable features: EA and WE features significantly contribute to these operational cost savings in terms of cost of electricity and water, while MR and IEQ features contribute to save landfill waste and carbon footprint, respectively. Therefore, these findings suggest that the uptake of green buildings using above sustainable features could be beneficial in the long run.

Looking into the achievement levels, cost contributions and saving potentials during the building life-cycle, the above sustainable features and their sub features could be recommended to implement in green buildings as their savings offset the construction cost of green buildings.

6 | CONCLUSIONS

Based on the two case studies analysed, the study recommends sustainable features including their sub features that have less contributions in terms construction and maintenance costs such as WE, SS and MR, and sustainable features that contribute significantly to construction and maintenance costs and offset these costs through the operational savings during the life-cycle such as EA and IEQ. Therefore, the current study recommends, green building investors to integrate sub features such as optimize energy performance, green power, measurement and verification, construction IAQ management plan—during construction, daylight and views, materials reuse, building reuse—existing elements, recycled content, construction waste management, water-efficient landscaping, alternative transportation—low–emitting and fuel-efficient vehicles, heat island effect non-roof, site development—protect or restore habitat and stormwater design—quantity control, for a given construction considering their respective contributions to the LCC of green buildings rather than their contribution to the construction cost.

However, these findings are based on two single case study buildings; therefore, recommend further study with more case studies. Further, the current study is based on the analysis of implications of sustainable features on LCC of two green industrial manufacturing buildings constructed in Sri Lanka. However, the comparison of green buildings' LCC with conventional buildings could provide more meaningful answers to what extent the implications of sustainable features affect to the discrepancy between the cost of green and conventional buildings. Therefore, the current study recommends future studies to compare LCC of green versus conventional buildings. In terms of operational cost, the study discovered that the implications of sustainable features are minimal; hence these implications were not further discussed in the current study. However, one can go for such in-depth studies and discover the implications of sustainable features on operational costs in terms of utilities, administrative cost, insurance and taxes. Further, it is little doubt that implications on operational savings and maintenance costs are supported purely by integrated sustainable features. Although the study selected two cases which are identical in terms of the most influential factors, one could argue that differences in the operation level of major building services and systems and end-user behaviours could also influence the O&M costs of buildings. Authors, therefore, suggest that future studies consider the influence of these factors on the cost of green buildings.

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