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Sustainability Assessment by Green Building Rating Systems: A Comparative Analysis of LEED, BREEAM and CASBEE on a Case Study

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Abstract
The construction sector, with its environmental impacts, such as energy consumption and pollution, urgently needs to adopt sustainable strategies to counter global warming. The global shift towards green buildings, significantly in developing countries, emphasises environmentally friendly structures that balance environmental, societal, and economic impacts, with green building rating systems pivotal in these efforts. This study aims for sustainability in the construction industry using green rating tools, focusing on a case study of a 5-story residential building assessed using LEED, BREEAM, and CASBEE standards. The building secured the highest ratings with LEED (42.72%), followed by BREEAM (40.03%), and CASBEE (33%) achieving "GOLD", "GOOD", and "GOOD" ranks respectively. Notably, the innovation and energy sectors offer room for enhanced rating. While all tools prioritise indoor environmental quality, comparative analysis of rating assessments and the three-dimensional sustainability and its association with rating tools reveal that they do not ensure economic sustainability while addressing environmental and social sustainability. This study provides insights into the efficacy of these rating tools and highlights areas for improvement to achieve sustainability ratings.

Keywords: Sustainable Construction, Green Building, Sustainability Rating Tools

1. Introduction

1.1 Background:

The construction industry, a significant contributor to GDP, heavily relies on the continuous depletion of natural resources. As environmental challenges such as climate change, emissions, and loss of biodiversity escalate, there's a pressing need to embed sustainability within this sector. Disturbingly, the construction domain is responsible for 1/3 of global greenhouse gas emissions and by 2035, global carbon emissions could reach a staggering forty-two billion tons [1]. The WGBC highlights that the construction industry accounts for 39% of global carbon emissions and predicts a 50% surge in energy demand by 2050. Moreover, this sector utilises half of the world's materials, consuming 42.4 billion tons annually. Hara et al. [2] stated three aspects of sustainability: environmental (emphasising energy and resources), economic (cost and safety performance), and social (encompassing education, culture, and well-being). Given the growing environmental concerns, there's a global shift towards green buildings, necessitating the rapid development of assessment systems and rating tools. Green buildings, pivotal for advancing sustainability in construction, emphasize resource efficiency, environmental impact reduction, and the principles of reuse, recycle, and reduce throughout their life cycle [3].To evaluate their

sustainability quotient, green rating assessment systems have become indispensable. Several global certification tools are available, with some gaining immense popularity for their emphasis on buildings' energy performance and environmental implications [4]. Thus, facilitating easy access to these tools, which assess buildings based on criteria like water and energy efficiency, materials, and emissions, is imperative for driving sustainable construction practices [1].
The concept of sustainability entails the capacity to subsist in a perpetual condition, fulfilling the requisites of the current generation, without resorting to the resources of future generations in order to surmount forthcoming challenges [5]. Sustainability can be delineated into three facets: environmental, social, and economic [5]. The environmental aspect of sustainability pertains to the endurance of natural resources and the ecological milieu [6]. Social sustainability assumes responsibility for the communal well-being of residents and workers [7]. Lastly, economic sustainability concerns the financial viability of construction expenses, encompassing both the initial direct and indirect costs of the undertaking, as well as the operational expenses throughout its lifespan [8].

1.2 Green Building Rating Tools:

Rating systems are mechanisms that evaluate sustainability using various indicators, offering a structured framework for sustainable development [9]. These environmental assessment methods bolster building efficiency [10], with sustainability tools predicting the impact of processes on sustainability facets. The GBRS is gaining traction globally due to its diverse applications [11]. These tools have dramatically influenced the construction industry, fostered sustainable construction, and enhanced building performance. While numerous global sustainable building programs address building functionality and its environmental impact [12], each rating system has its unique assessment process, evaluation instruments, and scoring methodology [13]. Projects certified by these systems typically showcase enhanced accommodation, reduced energy consumption, and increased overall value [14]. Green construction measurement tools assess building performance throughout their lifecycle, from planning to demolition [15]. Despite their contributions, these tools sometimes face criticism for overlooking certain social and economic factors [9]. GB assessment tools cater to diverse building types, like residences, hospitals, schools, and offices [16]. As the construction landscape evolves, incorporating new technologies and best practices, rating systems also adapt. However, due to climatic variations and distinct requirements, GBRTs differ in their assessment methods across countries [17]. Implementing these tools in buildings can reduce their environmental impact, with potential energy savings reaching up to 40% annually [18]. The GBRS serves as a public indicator of environmental sensitivity, reflecting the nature of used materials and employed standard practices [19]. These tools, often tailored to specific geographical and climatic conditions, manifest the regional differences in sustainability perspectives [20]. Key features of these tools include their origin country, overseeing organization, version history, and assessment categories. The table below shows the major green building assessment tools and their key features.

Table 1: Assessment Tools [14]

GBRT	BREEAM	LEED	CASBEE
Country	UK	US	Japan
Organizations	BRE	USGBC	JSBC
First version	1990	1998	2002
Latest version	2016	2013	2015

Major Categories	Energy Transport Water Health and Well-being Waste Pollution Land Use and Ecology Management Innovation	Energy Material Indoor Environmental Quality Regional Priority Water efficiency Sustainable Sites Innovation Integrative Process Transportation	Indoor Environment Quality Energy Efficiency Resource Efficiency On-site Environment

1.3 Comparison of Green Building Rating Tools:

Green construction measurement tools, such as BREEAM, LEED and CASBEE, differ in their criteria of assessment. BREEAM surpasses others in property management, health, and wellness considerations [30]. While BREEAM and LEED are on par in energy and transport scores. In contrast, CASBEE tools receive more emphasis on service quality than LEED and BREEAM. BEAM Plus allocates only 8% to material factors, in stark contrast to LEED's evenly distributed weightage [22]. CASBEE encourages composite materials in concrete while BREEAM offers credits for diverse materials [31]. Concerning energy, tools can be grouped based on energy demand reduction, renewable energy use, and environmental benefits. LEED, and BREEAM allocate approximately 8%, and 11% of their credits to energy efficiency [33].

1.4 Three-Dimensional Sustainability and RTs:

Green building assessment tools do not equally address all aspects of sustainability. Despite the equal significance of the three fundamental pillars of sustainability (environmental, social, and economic), these pillars are not equally prioritized in rating tools [20]. Rating systems primarily emphasize the environmental aspect, while the social aspect is also taken into account to some extent, but the economic aspect is given little importance [34]. Only LEED and BREEAM consider economic aspects in the allocation of credit points [29]. Therefore, the Triple Bottom Line of sustainability should receive equal attention in rating tools for sustainability assessment.

Table 2: Three-Dimensional Sustainability and GBRTs [17]

GBRS	Environmental (%)	Social (%)	Economic (%)	Others (%)
BREEAM	74.62	16.15	2.31	6.92
LEED	74.59	18.03	0.82	6.56
CASBEE	25.00	17.95	0.00	57.05

1.5 Problem Statement:

The carbon footprint of the construction industry is becoming more worrisome, significantly affecting climate change, natural resource depletion, greenhouse gas emissions, and energy usage. Notably, current human consumption rates surpass natural ecosystems' regenerative capacity by 1.7 times. Given the construction industry's distinctive nature, there's a pressing need to incorporate sustainability within its framework. Green buildings exemplify this by ensuring resource efficiency, but our country has yet to fully adopt rating tools that gauge sustainability in building sector. Thus, embracing green building practices and utilizing green building rating tools are pivotal to reducing environmental impacts and fostering sustainable construction methodologies.

1.6 Research Objectives:

The primary goal of this research is to address sustainability concerns within the building sector through the utilization of green building assessment tools. To achieve this overarching objective, the following specific aims have been defined:

- The utilization of various rating instruments for the sustainability of the chosen empirical investigation.
- Attainment of green rating credits or level.
- Assessment and comparison of tools for sustainability evaluation to comprehend the mechanisms and contributions of green ratings.

2. Methodology

A preliminary study and comprehensive literature review were conducted. After the selection of the case study, required data was collected. After applying the rating tools assessments, a detailed individual, as well as comparative analysis, was performed. The detailed methodology is shown in figure below.

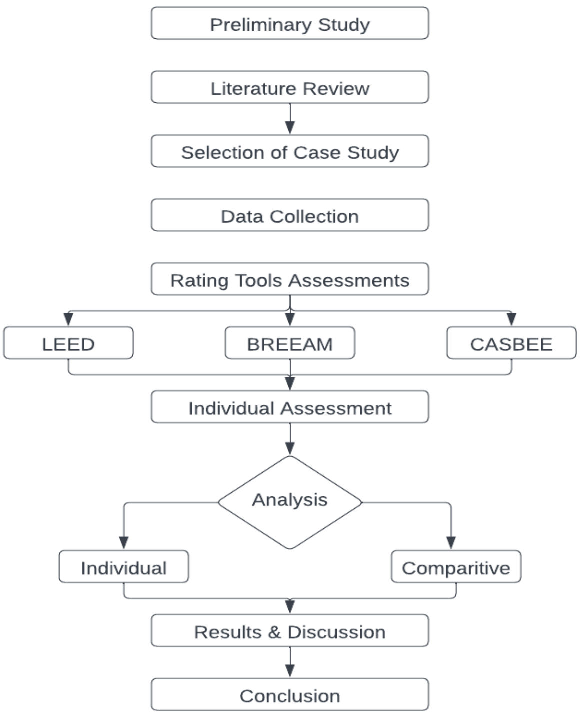

Figure 1: Summary of Research Methodology

This study involved two types of data: primary and secondary data. The details of the data are mentioned in the table below.

Table 3: Data Types and Sources of Data

Sr. No	Type	Details	Sources
1.	Primary Data	Bills of Quantities Tender Drawings System Manuals	Concern Organization Concern Organization [35],[36],[37],[38]
2.	Secondary Data	On-Site Assessment Data	Site Visits

2.1 Selection of Case Study

To investigate sustainability within the construction sector, a residential building was chosen for assessment. This frame structure building consists of five storeys, with the ground floor covering an area of 5450ft^2. Detailed information such as tender drawings, and BOQ were obtained from the relevant organization. Additional data was collected through on-site assessments, questionnaire surveys, and interviews conducted with both clients and contractors. The selected green building rating tools represent advanced systems widely adopted by developed countries and followed by many other nations. These tools were specifically chosen due to their accessibility and user-friendly manuals that facilitated a comprehensive understanding of the assessment process. By selecting this building for evaluation based on its suitability for our research objectives, we ensured both adequate access to various components within the building as well as compatibility with our sustainability assessment requirements.

2.2 Rating Tools Assessment

Three assessment tools, LEED, BREEAM, and CASBEE, were chosen based on their relevance, applicability, and measurement parameters. GBRTs have distinct categories and sub-categories for assessment. Every category has credit points determined by the tool's priority.

LEED:

LEED encompasses various criteria, with some being prerequisites for rating assessment. These criteria are categorized into eight main and several sub-categories. Each category, excluding prerequisites, offers points that depend on the case study's performance. The number of attainable credits varies by location (e.g., country), influencing the building's overall ranking, which is determined by the cumulative credits earned.

Table 4: LEED Assessment Categories [35]

Criteria	Points Available
Regional Priority	4
Material Resources	8
Innovation	6
Indoor Environmental Quality	17
Water Efficiency	12
Location and Transport	15
Sustainable Site	10
Energy and Atmosphere	38
Total	110

BREEAM:

BREEAM consists of various assessment measures organized into assessment issues, with nine core assessment parts and an additional Innovation category for earning credits. Each criterion assigns a specific number of attainable assessment credits based on compliance levels. Notably, minimum performance thresholds are set within each criteria framework to address critical environmental concerns. The cumulative percentages from all categories, including the Innovation section, determine the final rating classification for the building.

Table 5: BREEAM Assessment Categories [36]

Criteria	Points Available
Transport	18
Waste	4
Water	40
Innovation	10
Materials	26
Land Use and Ecology	6
Health and Wellbeing	33
Energy	108
Pollution	22
Total	267

CASBEE:

CASBEE employs multiple sets of criteria to assess a building's environmental performance. These criteria are further divided into sub-categories addressing specific environmental concerns. These categories and sub-categories contribute to the main assessment factors: environmental quality (Q) and environmental load (LR). A standardized assessment scale is applied to each criterion, determining the building's performance level. The final score across all categories reflects the values of Q and LR, which, in turn, are used to calculate the BEE and classify the building's rank.

Table 6: CASBEE Assessment Categories [37]

Category	Points Available
Environmental Quality of Building	Q
Indoor Environmental Quality	Q_1
Quality of Service	Q_2
Outdoor Environmental Quality	Q_3
Environmental Load Reduction of Building	LR
Energy Use	LR_1
Resource and Materials Use	LR_2
Off-site Environment Quality	LR_3

2.3 Assessment Criteria:

LEED

LEED is a renowned US tool for assessing building sustainability. Upon applying LEED to a building, it awards credit points, which indicate the building's sustainability level. No certification is awarded on points less than 27.

Table 7: LEED Certification Criteria [35]

Points	Rating
27-33	Certified
34-39	Silver
40-52	Gold
52-70	Platinum

BREEAM

BREEAM, a UK-based sustainability rating assessment tool, evaluates a building's sustainability level. BREEAM ratings are based on reaching a predefined percentage of threshold points during the building assessment. For a building to be classified, it must achieve a minimum score of 10% of the threshold, emphasizing a 10% acceptability threshold.

Table 8: Point Distribution Criteria by BREEAM [36]

Rating	Score (%)	Star Rating
Outstanding	≤ 85	******
Excellent	$70 \leq$ score ≤ 85	*****
Very Good	$55 \leq$ Score ≤ 70	****
Good	$40 \leq$ Score ≤ 55	***
Pass	$25 \leq$ Score ≤ 40	**
Acceptable	$10 \leq$ Score ≤ 25	*
Unclassified	Less than 10	----

CASBEE

CASBEE, a Japanese sustainability rating assessment tool, comprehensively assesses a building's environmental performance and assigns grades. The grading is determined through BEE values, calculated using specific equations.

$$\text{BEE} = \frac{\text{Building's Environmental Quality (Q)}}{\text{Building'sEnvironmental Load (L)}}$$

Whereas

$$\text{Building's Environmental Quality (Q)} = \frac{\sum (\text{Q1}, \text{Q2}, \text{Q3})}{3}$$

$$\text{Building'sEnvironmental Load (L)} = \frac{\sum (\text{LR1}, \text{LR2}, \text{LR3})}{3}$$

Table 9: CASBEE Grading Criteria [37]

Rating	Assessment	Score (%)	Star Rating
'S'	Excellent	3.0 or greater and (Q=50) or more	*****
'A'	Very Good	1.5-3.0 or 3.0 or greater and Q < 50	****
'B+'	Good	1.0-1.5	***
'B'	Fairly Poor	0.5-1.0	**
'C'	Poor	< 0.5	*

2.4 Sustainability Rating Assessment:

The sustainability assessment of a building serves to evaluate its environmental friendliness. In this study, the assessment of a case study is conducted using rating systems, which encompass various categories such as management, water efficiency, sustainable sites, energy efficiency, transportation, innovation, and material aspects, among others. Each category and its sub-categories are assessed individually through data analysis and site surveys, resulting in ratings awarded by the selected tools. These ratings reflect the sustainability level of the case study. Furthermore, a comprehensive comparative analysis is performed to identify the main and least focused categories across the rating tools, determine certification variations, and ascertain which rating tool indicates higher sustainability for the case study. Additionally, a triple-bottom-line comparison is undertaken to assess the environmental, social, and economic sustainability percentages in connection with the rating tools.

3. Results and Discussion

This section explains two phases. The Individual and comparative analysis of all selected rating tools.

3.1 LEED Assessment:

The research involves a comprehensive sustainability assessment of a case study using LEED, examining nine specific categories. Each category includes detailed specifications for evaluating the sustainability of the building.

Regional Priority:

Regional priority, which addresses public health, local environmental, and social equity concerns in the area, grants credit to the residential building within the case study. In this case, one credit is awarded out of four due to the absence of nearby healthcare facilities, specifically, the lack of a nearby hospital.

Location and Transport

The location and transportation category focuses on assessing occupants' transportation habits with the aim of promoting sustainable transportation practices. The primary goal of this category is to reduce pollution by minimizing the use of personal vehicles. The assessment criteria for this category are shown in the table.

Table 10: Alternative Transportation Rate Points

Alternative Transportation Rate	Points
10%	3
15%	4
20%	5
25%	6

30%	7
35%	8
40%	9
45%	10
50%	11
55%	12
60%	13
65%	14
70%	15

In the selected residential building with a total of 60 occupants from 11 families, a survey revealed that 55% of the occupants opt for alternative transportation methods instead of personal vehicles. Based on these findings, the research obtained 12 out of 15 possible credits in this category. The following is the data obtained after the survey shown in the table.

Table 11: Transportation Pattern of Occupants

No. of Occupants	Transportation Mode
45%	Personal Vehicle
14%	Public Transport
6%	Rideshares
35%	Biking or Walking

Material Resources

The material resources category focuses on minimizing embodied energy and material-related impacts throughout all construction phases. Detailed assessment criteria for this category are provided in a table.

Table 12: Assessment Criteria for Material Resources

Materials and Resources Points	Points Available	Points Achieved
Ongoing Purchasing and Waste Policy	Required	Available
Maintenance and Renovation Policy	Required	Available
Purchasing-Ongoing and Lamps	2	0.5
Purchasing-Facility Management-Ongoing, Maintenance and Renovation	2	1
Solid Waste Management-Ongoing, Maintenance and Renovation	7	2
Total	8	3.5

Within this category, consisting of 8 credits, there are two prerequisites related to material waste and renovation policies, both of which the case study complies with. Further subdivisions include ongoing lamp purchasing (2 credits), maintenance materials purchasing (2 credits), and ongoing maintenance of solid waste management (4 credits). Through detailed engagement with the contractor and adherence to materials specifications in the Bill of Quantities, the case study earned 0.5 credits for ongoing and lamp purchasing and 1 credit for maintenance material purchasing. However, as there is no specific materials recycling process in place, this criterion received only 2 credits.

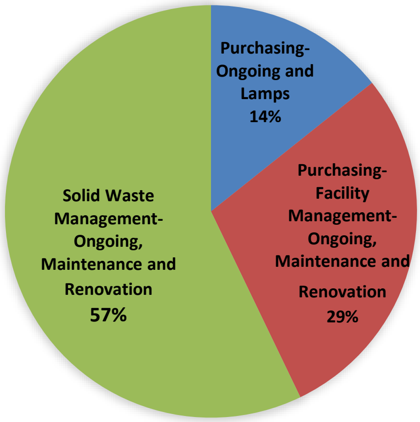

Figure 2: Proportion of Each Component

The total credit achieved in this category is 3.5, indicating an efficiency of 43.75% for the building in this aspect. The percentages of contributions in the material and resource categories are illustrated in a figure.

Innovation:

The Innovation category addresses additional green or sustainable features in the building beyond the standard rating system criteria. After a thorough examination of primary and secondary data, it was determined that there were no innovations in the selected case study beyond LEED criteria. Furthermore, there was no LEED professional involved in this case study, resulting in a total of 0 credits earned in this category out of the available 6.

Water Efficiency:

The Water Efficiency category focuses on the intelligent utilization of water both inside and outside the building. It emphasizes the use of greywater, water recycling, and water-efficient devices. Detailed assessment criteria for this category are provided in a table.

Table 13: Assessment Criteria of Water Efficiency

Water Efficiency Credits	Available Points	Achieved Points
Indoor Water Use Reduction	Required	Available
Building Level Water Metering	Required	Available
Outdoor Water Use Reduction	2	2
Cooling Tower Water Use	3	3
Indoor Water Use Reduction	5	2
Water Metering	2	2
Total	12	9

Within this category, there are two prerequisites related to water savings: one regarding the reduction of indoor water usage, meeting standards for toilet and urinal purposes, and the other related to water metering. The first prerequisite is fulfilled with fixtures meeting the standards (1.6gpf for toilets and 1gpf for urinals), and the second prerequisite is met with water meters installed for measuring potable water in the residential building. The reduction in indoor water usage earns 2 credits, following a detailed examination of plumbing drawings to confirm fixture compliance.

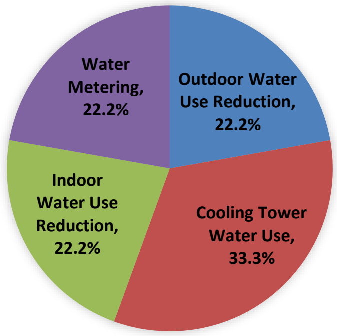

Figure 3: Proportion of Components

Outdoor water usage reduction in the building, earning 2 credits, is attributed to the absence of excess vegetation outside the structure. Since there is no combined cooling system requiring water, 3 credits are secured. The presence of a water meter for measuring consumption results in 1 credit earned. In total, the category garners 9 out of 12 credits, indicating a 75% efficiency for the building in this aspect. A figure illustrates the percentage contribution to water efficiency.

Indoor Environmental Quality:

Indoor Environment Quality pertains to the health and well-being of building occupants, encompassing factors such as thermal comfort, acoustic conditions, interior lighting, and quality views. Detailed assessment criteria for this category are provided in a table.

Table 14: Assessment Criteria of Indoor Environmental Quality

Indoor Environmental Quality	Available Points	Achieved Points
Environmental Tobacco Smoke Control	Required	Achieved
Green Cleaning Policy	Required	Acceptable
Minimum Indoor Air Quality Performance	Required	Achieved
Daylight and Quality Views	4	4
Integrated Pest Management	2	1
Thermal Comfort	1	0.5
Indoor Air Quality Management Program	2	1
Occupant Comfort	1	1
Interior Lighting	2	1
Green Cleaning- Custodial Effectiveness Assessment, products, and material, and equipment	3	0
Enhanced Indoor Air Quality Strategies	2	1
Total	17	9.5

Within the Indoor Environment Quality category, there are three prerequisites. The first, concerning good indoor air quality, is met as more than 4% of window area is available compared to the total floor area of each room. The second prerequisite, related to a smoke-controlled environment, is satisfied through the presence of smoke-prohibited signage and a smoking restriction within 7 meters of the building area. The third prerequisite, the cleaning policy, is also met.

The management program for indoor air quality is available, but its on-site implementation is lacking, earning only 1 credit. Strategies for improving indoor air quality are in place, resulting in 1 credit. For thermal comfort, a single credit is awarded since the only strategy employed is air conditioning. Internal lighting earns only 1 credit, falling short of the required four strategies. Daylight measurement, utilizing a lux meter at 2.5ft above the floor level, earns 2 credits. Additionally, the case study benefits from windows in 50% of occupied spaces with clear views of the sky and movement, resulting in 2 credits.

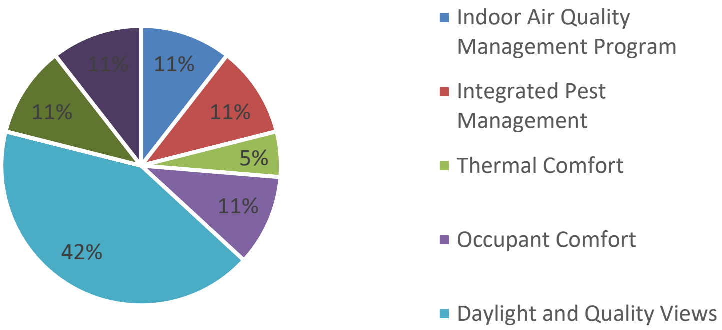

Figure 4: Proportion of Component

No green cleaning products, equipment, and procedures are implemented, resulting in zero credits earned. Pest management lacks a specific procedure, earning only 1 credit. However, occupants find comfort in the aspects outlined in this category, which adds 1 credit. In total, the category garners 9.5 credits, reflecting a 55.8% efficiency for the building in this aspect. A figure illustrates the percentage contribution to indoor environment quality.

Sustainable Sites:

The Sustainable Sites category focuses on preserving the natural environment's significance throughout the building's life, emphasizing that the outdoor environment should also complement the indoor environment. Detailed assessment criteria for this category are provided in a table.

Table 15: Assessment Criteria of Sustainable Cities

Sustainable Sites Points	Available Points	Achieved Points
Site Management Policy	Required	Available
Heat Island Reduction	2	2
Rainwater Management	3	0
Site Development-Protect or Restore Habiat	2	0
Site Management and Improvement Plan	2	1
Light Pollution Reduction	1	0
Total	10	3

In this category, there is one prerequisite concerning site management policy, which the case study successfully meets. However, for habitat restoration, as there is no vegetation in the building area, zero credits are earned.

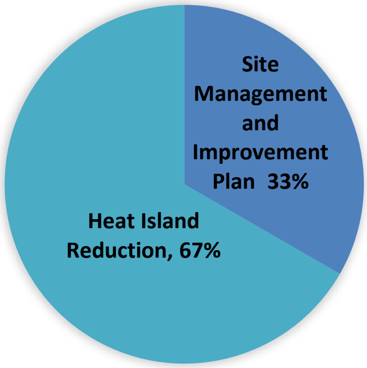

Figure 5: Proportion of different Component

Based on the examination of drawings, no rainwater storage tank is present in the building, resulting in zero credits earned in this sub-category. However, more than 50% of the parking spaces are covered, earning 2 credits for reducing heat island effects. Unfortunately, no on-site strategy is in place to reduce light pollution at night, contributing to zero credits. The site management and improvement practices have resulted in 1 credit, although they are not fully implemented. In total, the category achieves 1 credit, indicating a 30% efficiency for the building concerning sustainable sites. A figure illustrates the percentage contribution to a sustainable site.

Energy and Atmosphere

The Energy category focuses on the building's energy consumption patterns, energy analysis, energy efficiency, and optimization, with the primary goal of minimizing energy usage and incorporating renewable energy sources. The category encompasses four prerequisites, all of which are met, either directly or indirectly. The case study earns 4 credits for commissioning analysis and energy improvement applied before operation. However, no ongoing commissioning was noted during the assessment, resulting in no credits. Energy optimization is absent in the selected case study, and its energy usage resembles that of conventional buildings, offering no improvement and thus, no credits. Each family has individual energy meters with access to consumable energy data, leading to 2 credits. The presence of solar panels and energy storage batteries to reduce peak demand results in 3 credits. Unfortunately, there is no refrigerant management system or carbon offsets, contributing no credits. In total, the category achieves 9 credits, indicating a 23.6% efficiency for the building in the context of energy consumption.

Table 16: Assessment Criteria Energy and Atmosphere

Energy and Atmosphere	Credits Available	Credits Achieved
Energy Efficiency Best Management Practices	Required	Available
Minimum Energy Performance	Required	Available
Fundamental Refrigerant Management	Required	Available

Building-Level Energy Metering	Required	Available
Existing Building Commissioning Analysis	2	2
Existing Building Commissioning Implementation	2	2
Ongoing Commissioning	3	0
Optimize Energy Performance	20	0
Advanced Energy Metering	2	2
Demand Response	3	3
Renewable Energy and Carbon Onsets	5	0
Enhanced Refrigerant Management	1	0
Total	38	9

A figure illustrates the percentage contribution to sustainable energy practices.

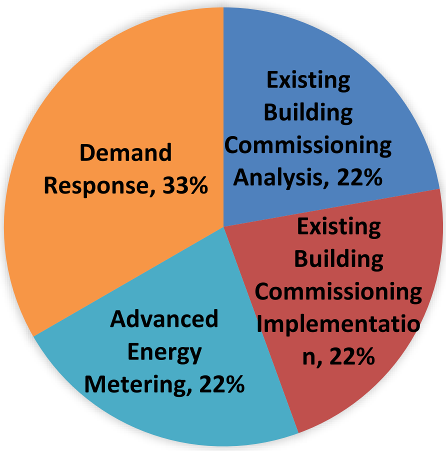

Figure 6: Contribution to Sustainable Energy Practices

Summary of LEED Assessment:

Table 17: LEED Assessment Summary

Category	Credits Achieved	Credits Available
Regional Priority	1	4
Location and Transport	12	15
Material Resources	3.5	8
Innovation	0	6
Water Efficiency	9	12
Indoor Environmental Quality	9.5	17
Sustainable Site	3	10
Energy and Atmosphere	9	38
Total	47	110

In the overall assessment, the case study has earned a total of 47 credits out of the available 110, achieving a percentage of 42.72%. This performance has led to the award of a GOLD certification. The graphical representation of credit percentages by LEED assessment is displayed in Figure.

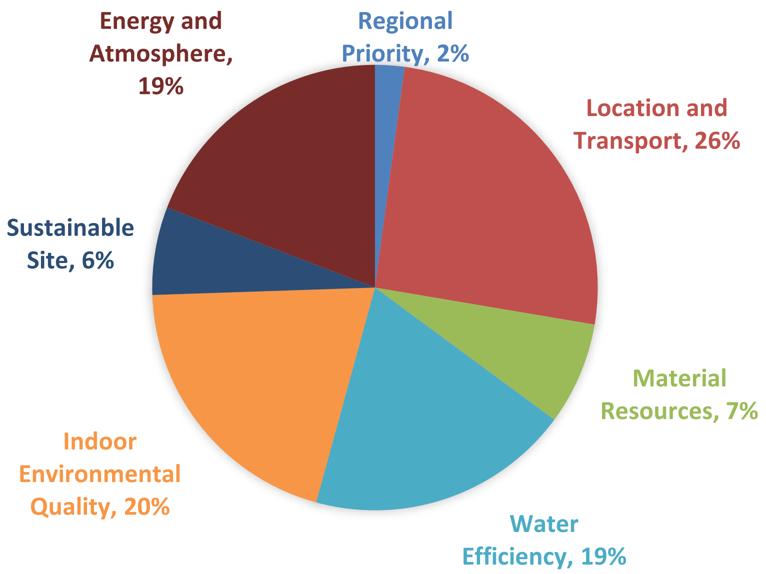

Figure 7: LEED Assessment Proportions by Categories

3.2 BREEAM Assessment:

The chosen case study underwent a comprehensive BREEAM assessment, which evaluated all sustainability-related categories and sub-categories.

Transport:

The transportation category focuses on occupants' transportation patterns, with the aim of promoting sustainable transportation. The assessment criteria, detailed in Table, prioritize reducing the use of personal vehicles to mitigate pollution. This assessment covers factors such as secure cycling facilities, public transport accessibility within 1km, amenities within 500m, and safe footpaths to reach public transport. In this case, all 18 credits were achieved, resulting in a 100% efficiency rating for the building.

Table 18: Transportation Rating

Transport	Points Achieved	Points Available
Cyclist Facility	4	4
Proximity to Public Transport	8	8
Proximity to Amenities	4	4
Pedestrian and Cyclist Safety	2	2
Total	18	18

Waste:

This category pertains to waste management and recycling efforts to repurpose materials. However, it lacks further subcategories. The building features specific waste bins for materials like glass and paper on each floor, yet it does not incorporate a recycling process, earning only 3 out of 5 available points in this category.

Water:

The water efficiency category emphasizes judicious water use indoors and outdoors, as well as the incorporation of greywater utilization, water recycling, and water-efficient devices within the building. Detailed assessment criteria for this category are provided in the table.

Table19: Assessment Criteria of Water

Water Credits	Points Available	Points Achieved
Water Meter	6	6
Water efficient equipment: WCs	4	4
Water-efficient equipment: urinals	4	4
Hand washing basins	4	4
Showers	4	4
White goods	4	0
Leak detection system	4	0
Leak prevention	4	0
Isolation valves	4	0
Reducing mains water consumption	2	0
Total	40	22

Water meters have been installed, securing 6 credits. Both water closets and urinals consume water below specified thresholds, each earning 4 points. Hand wash basins and showers comply with flow rate requirements, resulting in 4 credits for each category. However, there is no water leakage detection system, isolation valves, or strategies to reduce water consumption, thus earning 0 credits in those areas. Rainwater storage and usage are absent in the building.

Innovation:

The Innovation category pertains to green or sustainable features beyond rating system standards. In this case study, the building was designed and operated using conventional methods, with no observable innovations beyond BREEAM criteria. Additionally, there was no involvement of a BREEAM professional. Consequently, this category did not earn any of the available 10 credits.

Materials

The material resources category focuses on minimizing embodied energy and material impacts throughout all construction phases, emphasizing the use of sustainable materials. Detailed assessment criteria for this category are provided in the table.

Table 20: Assessment Criteria of Materials

Material Credits	Points Available	Points Achieved
Condition Survey	4	0
Security Advice	4	4
Intruder Alarm System	4	4
Alarm System Monitoring	4	2
Natural Hazards	4	4
Future Adaption	4	4
Designing for Robustness	2	0
Total	26	18

In the Material Resources category, the following specifications were observed: no condition survey was conducted according to occupants, earning 0 credits. Security issues were not measured, securing 4 credits. A 24-hour fire alert system is available, resulting in 4 credits. Although the alarm system operates continuously, specific monitoring is lacking, earning 2 credits. Plans for occupants on each floor to prevent natural hazards secured 4 credits. During the site visit, it was noted that future changes can be easily implemented where required, earning 4 credits. Additionally, there are pathways for occupants to navigate the building. The total points achieved in this category are 18 out of the available 26.

Land Use and Ecology:

The Sustainable Land Use category emphasizes environmentally responsible land utilization and the promotion of long-term biodiversity improvements in the vicinity of the building. Detailed assessment criteria for this category are provided in the table.

Table 21: Assessment Criteria of Land Use and Ecology

Land Use and Ecology	Points Available	Points Achieved
Planted Area	4	2
Ecological Features of Planted Area	2	1
Total	6	3

In this category, the building lacks a discernible vegetation trend, but approximately 10% of the area is green, earning 2 credits. A limited amount of plantation around the building contributes to an additional credit, resulting in a total of 3 credits out of the available 6.

Health and Wellbeing:

The Health and Wellbeing category is concerned with indoor environmental quality, encompassing occupant health, thermal comfort, acoustic conditions, interior lighting, and quality views. Detailed assessment criteria for this category are provided in the table.

Table 22: Assessment Criteria for Health and Wellbeing

Water Credits	Points Available	Points Achieved
Glazing	2	0
Glare Control	4	3
Thermal control	4	3
Ventilation controls	2	2
Microbial contamination	2	0
Water provisions	2	2
Indoor and/or outdoor space	4	4
Illuminance levels (Lux)	4	4
Lighting control	4	3
Inclusive design	3	3
Ventilation requirements	2	2
Total	33	26

No credits were awarded for the total glazed area due to the absence of an energy model. However, manual solar shading controls on all windows earned 3 credits for glare control. The only available option to regulate temperature is through window openings, earning 3 credits. Ventilators were installed for ventilation control, resulting in 2 credits. There was no strategy for contamination control, earning 0 credits in this sub-category. Provision of water for occupants in suitable locations contributed 2 credits. The presence of benches outside the building garnered 4 credits. Adequate illuminance levels, measured at 157 lux with compliance, secured 4 credits. Lighting control options in sockets, while not specified, earned 3 credits. Inclusive design features, such as a sloping entrance, handrails, and good entrance lighting, contributed 3 credits. The building's location, positioned 10 meters away from external pollution sources like roads, met ventilation requirements, earning 2 credits. In total, 26 credits were earned out of the available 33 in this category.

Energy

The Energy category is concerned with the building's energy consumption, analysis, efficiency, and renewable energy utilization. The goal is to minimize energy use and promote renewable energy sources. However, the client and contractor confirmed that the building lacks energy modelling and analysis due to its conventional design, resulting in 0 credits for energy analysis. Nevertheless, the presence of onsite solar panels, though with minor concerns, earned 4 credits. In this category, a total of 4 credits were earned out of the available 108.

Pollution

The Pollution category emphasizes the reduction of noise, light, and air pollution emitted from the building, as well as strategies to minimize pollution. In this case, no pollution prevention measures were identified, resulting in 0 credits in that sub-category. However, the building's location in a low flood risk area earned 4 credits. To mitigate pollution from surface water runoff, the building features an effective drainage system and permeable surfaces.

Table 23: Assessment Criteria for Pollution

Water Credits	Points Available	Points Achieved
Pollution Prevention	4	0
Flood Risk Assessment	4	4
Impact Mitigation	2	2
Impacts of Refrigerants	4	4
Leak Detection System	4	0
NOx Emissions	4	3
Total	22	13

4 credits were earned for using small-scale refrigerants, which pose no significant danger. However, no credits were awarded for the absence of a leakage detection system. The building doesn't engage in activities resulting in NOx emissions, but not to a 100% extent, thus securing 3 credits. In total, 13 credits were earned out of the available 22 in this category.

Summary of BREEAM Assessment

All BREEAM categories and subcategories have been thoroughly assessed, with notable weaknesses in the energy and innovation categories, as no credits were earned in these areas. The total score obtained is 107 points out of a possible 267, resulting in a percentage score of 40.0%. The achieved BREEAM certification is "GOOD."

Table 24: Summary of Assessment

Category	Points Available	Points Achieved
Transport	18	18
Waste	4	3
Water	40	22
Innovation	10	0
Materials	26	18
Land Use and Ecology	6	3
Health and Wellbeing	33	26
Energy	108	4
Pollution	22	13
Total	267	107

The graphical representation of the percentage of the credits by BREEAM assessment is shown in figure.

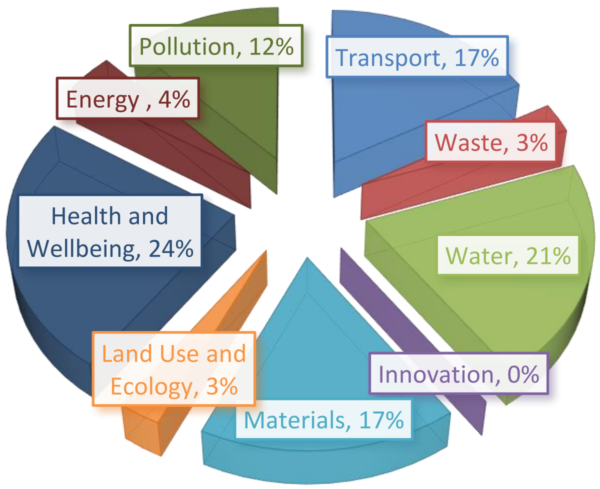

Figure 8: Percentage of Credits by BREEAM Assessment

3.3 CASBEE Assessment:

The chosen case study underwent assessment by CASBEE, with evaluations conducted across all categories and subcategories. Q environmental quality and LR environmental load were calculated, and credits/points were awarded based on performance. The passing threshold for all categories is set at level 3.

Indoor Environment (Q1)

- **Sound Environment:** Appropriate noise level in the building; no noise pollution from traffic; materials in the building absorb light and heavy sounds; achievement level: 3 out of 5.
- **Thermal Comfort:** Limited thermal control strategies; reliance on air conditioning; effective ventilation in lobbies; achievement level: 2 out of 5.
- **Lighting and Illuminance:** Sustainable building orientation with south and east-facing windows; efficient daylight usage; no daylight devices; glare control with blinds and awnings; illuminance level at 157 lux; no specific overall lighting control system; achievement level: 4 out of 5.
- **Air Quality:** Ventilators, appropriate window area, pollution source distance, and smoke detectors contribute to a level 4 achievement out of 5 in maintaining air quality.

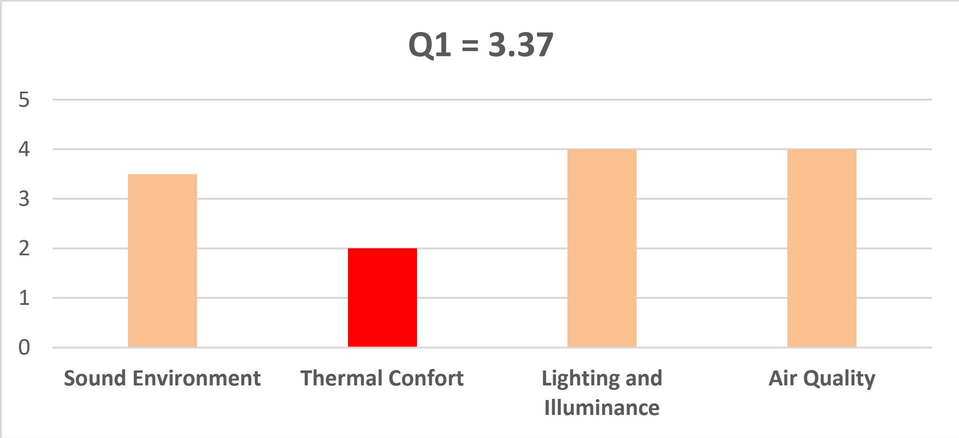

Figure 9: Indoor Quality Subcategories

Quality of Service:

- **Functionality and Usability:** Communication facilities, suitable ceiling height, maintenance strategies, and functions result in an achievement level of 3 out of 5.
- **Durability and Reliability:** Earthquake-resistant design with a lack of damping system, a refurbishment period of over 20 years for external walls, and the use of high-quality materials lead to a level 4 achievement out of 5.
- **Flexibility and Adaptability**: Standard floor-to-floor height and load capacity margin, along with ease for future plumbing, communication cable, and electrical wire renewals, result in a level 3.5 achievement out of 5.

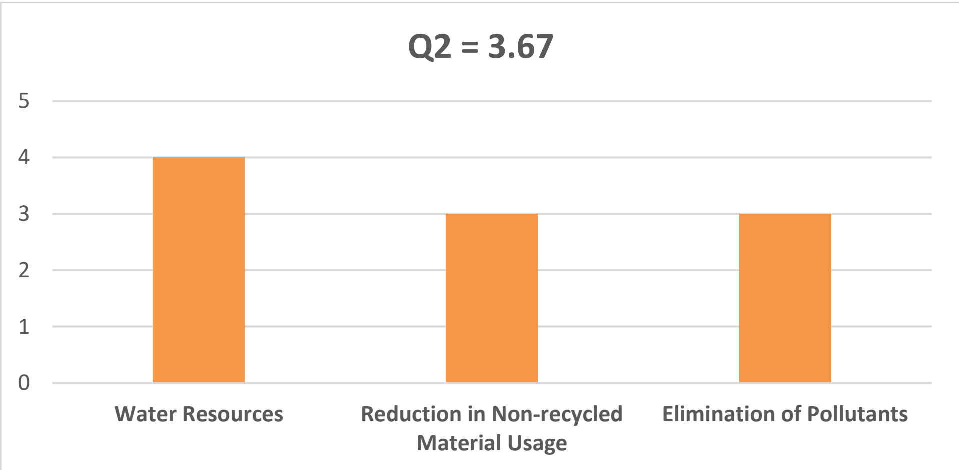

Figure 10: Quality of Service Subcategories

Outdoor Environment (Q3)

- **Preservation of Biotope:** The outdoor space has less than 10% greenery, but security cameras outside the building contribute to a level 4 rating out of 5.
- **Townscape and Landscape:** The building is visible from a nearby road without obtrusive roof equipment, achieving a level 4 out of 5.
- **Outdoor Amenity:** The use of locally available materials and the presence of a wind and light-passing balcony are notable, although there is no significant rain shelter outside the building, resulting in a level 2 rating out of 5.

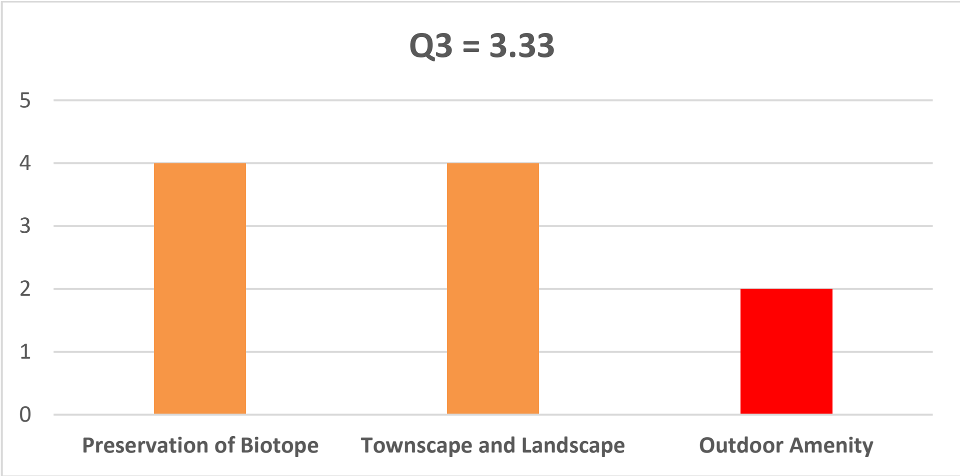

Figure 11: Outdoor Quality Subcategories

Energy (LR1)

- **Heat Control on the Out Surface of the Building:** The building employs eaves and other shading methods on windows for heat control. No specific heat control materials from the BOQ are used, resulting in a level 3 achievement.
- **Natural Energy Utilization:** Solar panels are installed on the roof for natural energy utilization, although no other measures are taken, resulting in a level 3 achievement.
- **Building Service System Efficiency:** There is no building model or energy analysis available to assess the energy efficiency of the residential building. The solar system is the sole energy-efficient system, leading to a level 1 achievement.
- **Efficient Operations:** The building is equipped with devices to monitor water, electricity, and gas consumption, providing cost data. The level achieved is 2 out of 5.

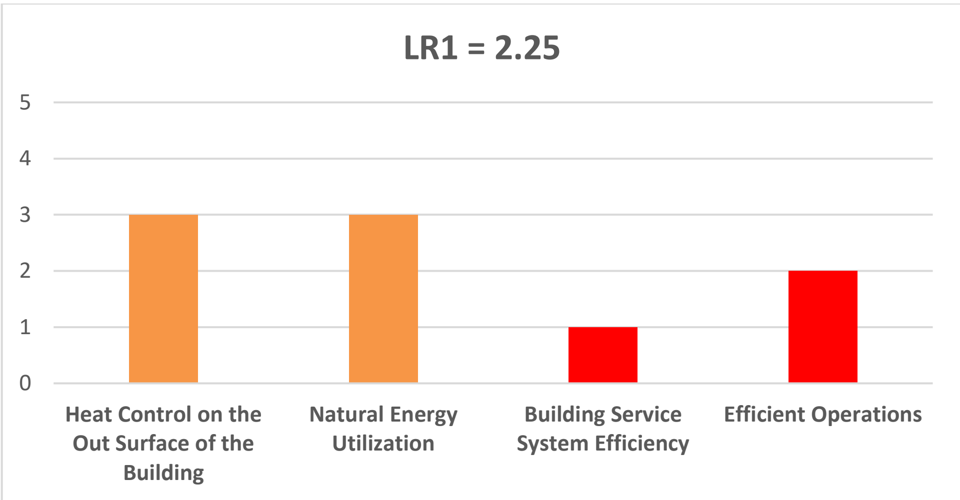

Figure 12: Energy Subcategories

Resource and Materials

Water Resources: The building uses water-saving toilets with a consumption of 4.5 litters per use and urinals with 1.2 litters per use. However, there is no rainwater storage system. The building falls under the category of less than 2000m³, achieving a level 4 out of 5.

Reduction in Non-recycled Material Usage: High-strength materials are employed in the building's structure, leading to an overall reduction in material usage. However, there is no provision for reusing the building frame during demolition, and no recycled materials are used. The building achieves a level 3 out of 5.

Elimination of Pollutants: The wall joints, tile joints, and wooden parts in the building do not incorporate pollutant materials. Additionally, the building relies on small-scale refrigerants for cooling, thus avoiding the production of hazardous gases. A level 3 is attained out of 5.

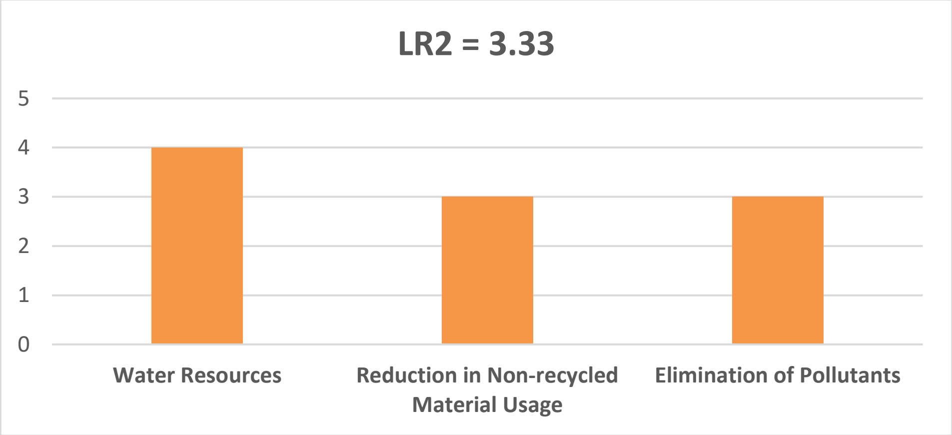

Figure 13: Resources and Materials Subcategories

Off-Site Environment (LR3)

Consideration of Global Warming: The building construction and operation phases do not incorporate considerations related to global warming. Level 1 is achieved for this category.

Regional Environment Considerations: Materials other than concrete in the exterior wall constitute less than 10% of the building. The roof area lacks evaporative materials but incorporates solar panels. The building achieves a level 3 out of 5.

Consideration of the Surrounding Environment: There are no administrative-level guidelines for sewerage load suppression and rainwater load reduction control. However, the building provides parking facilities and security for its occupants, leading to a level 3 achievement out of 5.

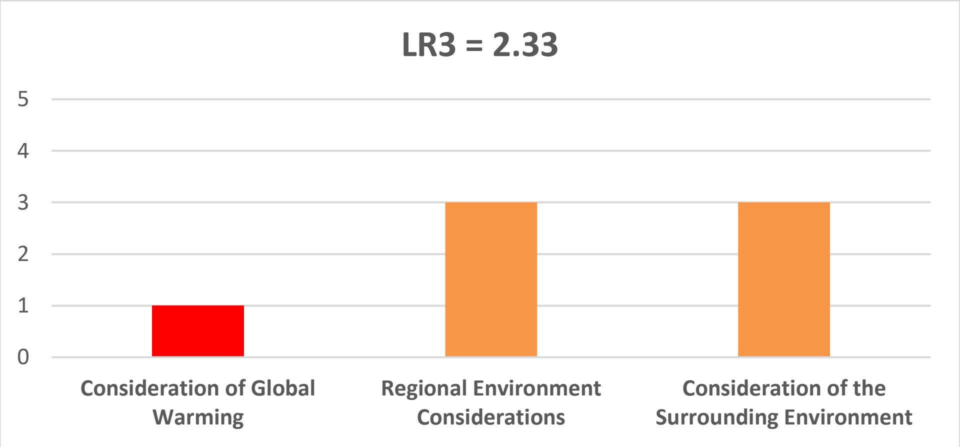

Figure 14: Off Site Subcategories

Radar Chart of Major Categories in CABEE

All Environment Quality (Q) categories, including Q1, Q2, and Q3, have been assessed and ranked. Likewise, Environmental Load Reduction (LR) and its categories, LR1, LR2, and LR3, have also been evaluated. The results are visually represented in a radar chart, as depicted in the figure.

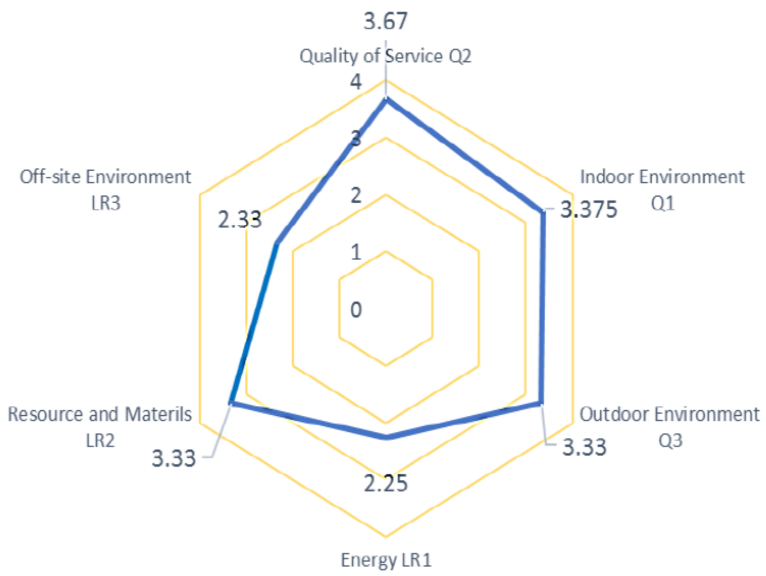

Figure 15: Radar Chart of Major Categories in CABEE

BEE Calculation and CASBEE Certification

Building Environmental Efficiency (BEE) is determined by assessing Q and LR, with their final values derived from SQ and SLR. Q is converted from a 1 to 5 scale to 0 to 100 using the formula Q = 25(SQ - 1), and LR is transformed from 0 to 5 to 1 to 100 with LR = 25(5 - SLR). The BEE value is computed formula.

$$BEE = \frac{Q}{L}$$

$$BEE = \frac{25 * (3.45 - 1)}{25 * (5 - 2.63)} = 1.03$$

Summary of CASBEE Assessment

All the building's environmental quality and load categories have been assessed and ranked. The Building Environmental Efficiency (BEE) value, calculated from the converted values of L and Q, is 1.03. This performance results in a B+ grade with three stars and a "Good" certification.

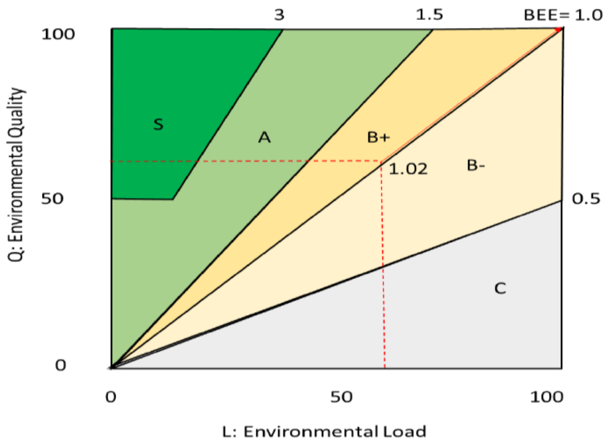

Figure 16: CASBEE Summary

3.4 Comparative Analysis of LEED, BREEAM and CASBEE:

The table provides a comparative analysis of the selected rating tools. Significantly, the energy category assumes paramount importance across all three rating assessment systems. However, the case study exhibits a deficiency in the energy category, chiefly due to its lack of energy modeling and analysis in several subcategories.

Table 25: Comparison between LEED, BREEAM and CASBEE

Categories	LEED	BREEAM	CASBEE
Site Aspects	3	3	6.6
Transport	12	18	-
Energy	9	0	4.5
Water	9	22	-
Material Resources	3.5	18	6.6
Indoor Environmental Quality	9.5	26	6.7
Pollution	-	13	-
Waste	-	3	-
Innovation	0	0	-
Off-Site Environment	-	-	4.6
Quality of Service	-	-	7.3
Regional Priority	1	-	-
Total Credit Available	110	267	BEE = 3
Total Credit Achieved	47	107	BEE = 1.03
Percentage Achievement	42.72%	40%	34%
Start Rating	-	3 Stars	3 Starts
Final Certification	GOLD	GOOD	GOOD (B+)

In the comparative study of green building rating tools, unique emphases become evident among LEED, BREEAM, and CASBEE. In the energy category, LEED awards the maximum, with 9 points, whereas BREEAM does not provide direct points, instead opting for a comprehensive approach through energy subcategories. In the realm of water conservation, BREEAM and LEED lead with 22 and 9 credits, respectively. CASBEE, however, does not include a specific category for water assessment.

Transportation facilities receive substantial attention in LEED and BREEAM, with respective point allocations of 12 and 18. All transportation-related subcategories in the presented case study were satisfied by these two systems. On the other hand, CASBEE incorporates some transportation elements within its off-site environment category.

Site aspects are consistently evaluated across the three systems. CASBEE assesses this domain under the onsite environment, providing significant points. In contrast, LEED and BREEAM have stringent criteria for this sustainability aspect. The material resources category sees LEED awarding a minimal 3.5 points, whereas assessment of CASBEE integrates certain water-related aspects.

While the management category isn't directly evaluated by either LEED or BREEAM in the selected building, CASBEE addresses management facets under its quality-of-service category. In the regional priority domain, only LEED specifically awards a point, but CASBEE includes regional considerations within its off-site environment category.

Pollution is predominantly addressed by BREEAM, with the case study earning 13 credits. CASBEE, on the other hand, integrates pollution considerations as pollutant emissions under its materials category, achieving a level 3 score. LEED does not have a dedicated pollution category.
All three tools assess indoor environmental quality. BREEAM is particularly generous, offering 26 credits, while LEED and CASBEE allocate 9.5 points and achieve a 3.37 level, respectively. Finally, while BREEAM focuses on waste with 3 credits, the other systems either do not have a discrete waste category or blend it into their materials and resources assessment.

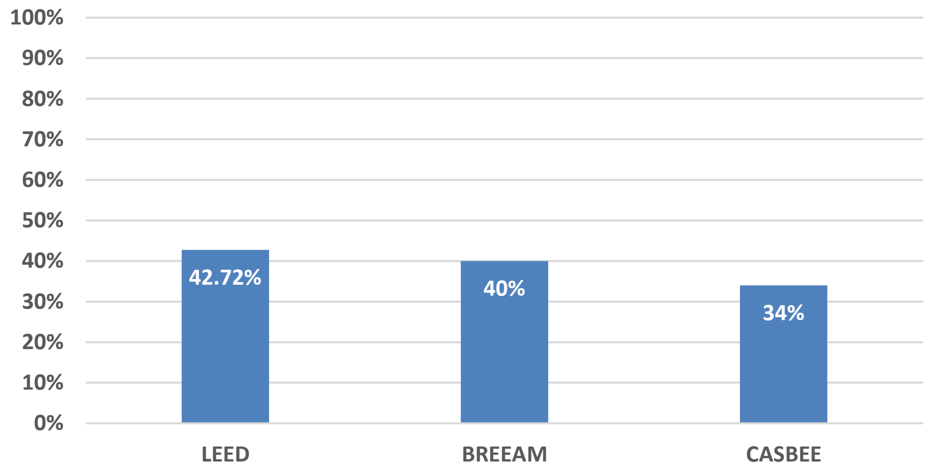

Figure 17: Comparison of Systems

Under LEED, the case study secured 47 credits out of a possible 110. This score positions it within the range qualifying for GOLD CERTIFICATION, hence the study is deemed GOLD CERTIFIED by LEED standards. BREEAM's evaluation resulted in the case study obtaining 107 out of 267 possible credits, translating to 40%. This score aligns with the GOOD RATING, equivalent to a three-star certification. CASBEE's assessment yielded the lowest performance for the case study. The BEE score derived was 1.02, narrowly aligning with the B+ grade, also reflecting a three-star ranking and a GOOD certification level.
In summary, while the case study's evaluations presented varied scores across the different tools, it achieved its highest credits under LEED. The consistent theme across the systems is the attainment of a three-star or equivalent rating.

3.5 Summary of Three-Dimensional Sustainability.

The concept of sustainability encompasses environmental, social, and economic dimensions. Following the evaluation of the selected case study through green building rating tools, a comparison is made for all three dimensions of sustainability and the rating tool. Table is presented to show the percentage score by each rating system that the selected building achieved.

Table 26: Triple Bottom Line

Sustainability Pillar	LEED	Score (%)	BREEAM	Score (%)	CASBEE	Score (%)
Environmental	Sustainable Sites Energy and Atmosphere Water Efficiency	22.30%	Land Use and Ecology Energy Water	23.60%	Energy Resource and Materials Outdoor Envi-	20.30%

Sustainability Pillar	LEED	Score (%)	BREEAM	Score (%)	CASBEE	Score (%)
	Material Resources		Materials Pollution Waste		ronment Offsite Environment	
Social	Indoor Environment Quality Location and Transport Regional Priority	20.43%	Transport Health and Wellbeing	16.43%	Indoor Environment Quality	6.10%
Economical	-	0.00%	-	0.00%	-	0.00%
Others	Innovative Construction	0.00%	Innovative Construction	0.00%	Quality of Services	6.60%
Total	42.73%		40.03%		33%	

Graphical representation of each pillar is shown in.

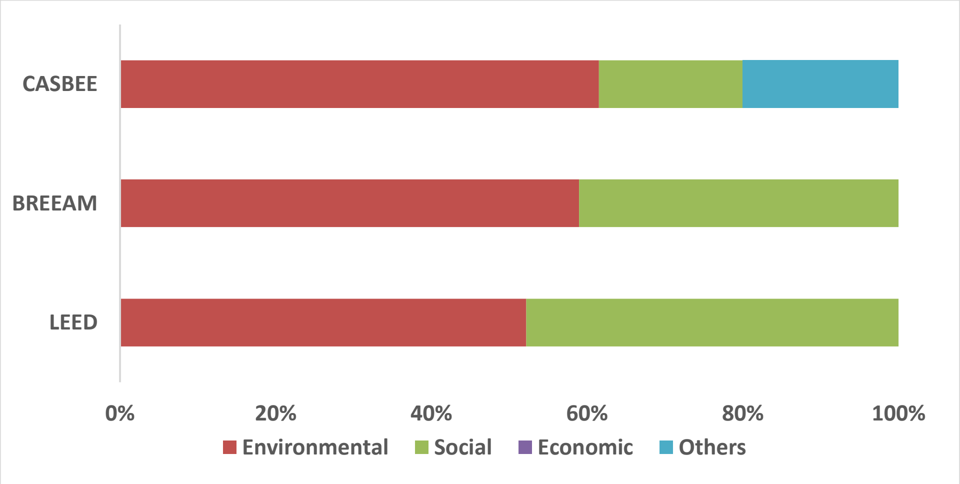

Figure 18: Triple Bottom Line

4. Conclusion:

The selected residential building attained a rating of 42.73% according to LEED, 40.03% by BREEAM. It's important to note that CASBEE evaluates using a different assessment pattern, emphasising a level scale over a points system. Nonetheless, when converted, the BEE value of 1.02 equates to about 33%, indicating a higher sustainability rating through LEED compared to the other systems. In terms of assessment performance levels, the selected case study was awarded GOLD, GOOD and GOOD by LEED, BREEAM and CASBEE respectively. While all the rating tools identified relatively similar performance levels, LEED's GOLD rating distinctly sets it apart from the others. Based on both individual and comparative analyses, it's evident that LEED is the most sustainable tool for evaluations within this region. Among all the evaluated categories in these three rating tools, energy and innovation were areas where credits were harder to come by. However, the LEED assessment did grant some credits under the energy category. It's worth noting that the energy category in other systems demands detailed modelling and analysis of energy for credit allocation, but such data was unavailable for the case study. Analysing sustainability dimensions, the building scored highest in the environmental aspect, followed by the social. Conversely, the economic dimension was found wanting. The insights from this study can prove invaluable for the construction sector, providing guidance on areas that need to be addressed to achieve superior sustainability rating assessments.

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