CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Comparative Analysis of Green Building Rating Systems for Sustainability Assessment of a Residential Building

by

Usman Hussain

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I want to dedicate this work to my family, who helped me throughout my education. This is likewise a tribute to our best teachers who guided us to go up against the troubles of presence with ingenuity and boldness, and who made us what we are today.

CERTIFICATE OF APPROVAL

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International Refereed Conference Articles

1. Hussain, U. and Gardezi, S.S.S. (2020). Sustainability Assessment of a house by using LEED and BREEAM. 11th International Civil Engineering Conference, NED, Karachi, Pakistan. March 13-14, Paper 72.

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Abstract

The construction industry has many adverse effects on the environment (e.g. energy usage, water pollution, air pollution etc). The building sector, due to the significant environmental footprints it creates, needs to adopt sustainable approaches to help prevent global warming and climate change. These impacts of buildings on the environment have run a global trend in the building industry to go green, which significantly promotes the development of the green building concept. In developing countries, green buildings are not as elaborate as required. Green buildings are termed as environmentally friendly buildings, which help to mitigate the impacts of buildings on the environment, society, and economy. Green building rating systems are one of the key tools required for such sustainable endeavors.

The main objective of the current research is to achieve sustainable development in the building sector by application of green rating assessment tools. The sustainability rating assessment of the selected case study has been performed by adopting five rating tools. A five-story residential building was selected as a case study. LEED, BREEAM, CASBEE, Green Star, and BEAM Plus standards were applied. The main and sub-categories of selected rating tools have been investigated by using primary and secondary data of the case study.

The current research found that the case study achieved maximum rating credits by LEED (42.72%), BREEAM (40%), CASBEE (34%), Green Star (40%), and BEAM Plus (40.4%). LEED achieved “GOLD” ranking, BREEAM “GOOD”, CASBEE “GOOD”, Green Star “GOOD” and BEAM Plus “BRONZE”, respectively. The innovation and energy criteria were observed to an aspect that can result in improves the rating of the selected case study. In the top five rating categories indoor environmental quality lies in each rating tool. A detailed comparative analysis has been conducted on the rating assessment results. A comparison is also made on the triple bottom line of sustainability and its association with rating tools. The results also indicated that environmental and social sustainability is achieved but economic sustainability is not achieved by any selected rating

tool. This study can be used to explore the rating assessment tools in the building sector and investigate the design attributes that lack to obtain sustainability rating assessment.

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Abbreviations

AHP	Analytical Hierarchy Process
ASGB	Assessment Standard for Green Building
BEAM	Building Environmental Assessment Method
BEE	Built Environment Efficiency
BIM	Building Information Modelling
BOQ	Bill OF Quantities
BRE	Building Research Establishment
BREEAM	Building Research Establishment Environmental Assessment Method
C	Celsius
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CC	Construction Costs
CLWC	Comprehensive List of Water Criteria
CWM	Construction Waste Management
D	Dimensional
EE	Environmental Evaluation
GB	Green Building
GBCA	Green Building Council of Australia
GBDFs	Green Building Development Factors
GBRS	Green Building Rating System
GBRTs	Green Building Rating Tools
GDP	Gross Domestic Product
GM	Green Mark

GMC	Green Mark Certificate Standard
GSAS	Global Sustainability Assessment System
GSBC	German Sustainable Building Council
HK	Hong Kong
HKGBC	Hong Kong Green Building Council
HQE	High Quality Environment
HVAC	Heat Ventilation and Air Conditioning
IAQ	Indoor Air Quality
IPCC	Intergovernmental Panel on Climate Change
ISBRS	Iran's Sustainable Building Rating System
JSBC	Japan Sustainable Building Consortium
LCA	Life Cycle Assessment
LCC	Life Cycle Costs
LEED	Leadership in Energy and Environmental Design
MS	Masters of Science
NZ	New Zealand
OC	Operation Costs
QSAS	Qatar Sustainability Assessment Tool
SA	South Africa
SB	Sustainable Building
SBAT	Sustainable Building Assessment Tool
SEAM	Saudi Environmental Assessment Method
SIRSDEC	Sustainable Infrastructure Rating System for Developing Countries
SPD	Site Planning and Design
UK	United Kingdom
US	United States
USGBC	United States Green Building Council
V	Volume
WGBC	World Green Building Council
Σ	Summation

Chapter 1

Introduction

1.1 Background

The construction industry is one of the major contributors to GDP. Natural resources are key elements of the construction sector which are depleting continuously. The concept of sustainability needs to be embedded in the construction sector due to the main environmental issues such as climate change, hazardous emissions, air pollution, increasing irregularity in rainfall, and loss of biodiversity. CO2 emissions degrade the environment in many ways, the construction industry also contributes in this regard. The building area utilizes one-third of the global sources, one-sixth of the world's freshwater, 40% of all raw materials and consumes 25% of the timber harvest [2]. Socio-economic and environment are extensively affected by the waste generated by the construction [3]. The construction industry also majorly contributes towards greenhouse gas emissions more than one-third of the total in the world. It is expected that by 2035, the global carbon emissions reach to 42.4 billion tons [4]. According to WGBC, the building sector accounts for global carbon emissions by 39% and 50% of energy demand will increase by 2050. Natural resources are largely exploited due to the rapid urbanization and growing demand of the building sector. According to WGBC, 50% of global material is used by the building sector, and also 42.4 billion tons of materials consumed annually.

Hara et al. [1] stated that three aspects of sustainability cover the following categories: such as environmental aspect in energy and natural resources, economic aspect in the performance of cost and safety, education, culture, and well-being as the social aspect of sustainability. As the environmental concerns and climatic challenges increasing very promptly, the intension towards green buildings also maximizes worldwide. In this alarming situation, many rating tools and assessment systems for green buildings developing rapidly. There is a need to introduce a sustainable building concept or green buildings concept in the construction sector.

For the growth of sustainability in the construction zone, green building is a fundamental concept [5]. Sustainable buildings concern a structure as well as the adoption of methods which reduces environmental impact and responsible for resource efficiency during all phases of building the life cycle. Green buildings are relevant to reuse, recycle, and reduce principal. For checking the sustainability rank of a green building, green rating assessment systems are one of the key tools required for such sustainable endeavors.

Various certification tools are available for buildings around the world. Some rating tools that are gaining popularity are expanding the awareness and the status of green buildings and the consequence of the energy performance to their environment and such project are being prepared for the next generation of buildings to comply with the new high standards [6]. Sustainable construction practices are very significant in the construction industry, therefore the ease to access to these rating tools should be mandatory [4]. These rating systems check the features in building like water efficiency, innovations, energy efficiency, indoor environmental quality, materials, and emissions to allocate a rating level.

1.2 Research Motivation and Problem Statement

Natural resources are depleting on a continuous scale. The construction industry plays a vital role in natural resource depletion as it consumes a major part in terms of construction materials. Buildings are a significant contributor to greenhouse gas emitters and extensively change the climate over time. As the construction industry growing rapidly, environmental degradation increases day by day as evident from the environmental footprint of buildings.

Therefore, the concept of sustainability needs to be introduced in the construction industry. Sustainable development is necessary to save our future. Moving towards sustainable development in the construction sector, green building is a very imperative technique. Green buildings are environment-friendly buildings. Buildings should be green to minimize environmental impact by them and to achieve a sustainable future. The level of sustainability of green building checks through some rating tools. Five rating assessment tools are used in this research. Thus, the problem statement is as follow:

Carbon footprint by the building sector is a major issue nowadays. This issue has a major effect on the environment. The construction industry has major environmental concerns: climate change, natural resource depletion, greenhouse gas emissions, and energy consumption. Presently, humans are consuming natural resources 1.7 times faster than ecosystems can generate. Due to the uniqueness of the construction industry by its nature, the concept of sustainability should be addressed in a construction industry framework. Green buildings integrate unique construction features that certify the efficient use of resources. Rating tools are not adopted for construction in our country to explore the lack of sustainability in construction. Therefore, green building practices and the application of green building rating tools can help to minimize the environmental influence and guide for sustainable practices in the construction zone.

1.3 Research Objective

The overall objective of the research program is sustainability concerns in the building sector by applying green building assessment tools.

The specific aims of this MS research are:

- Application of different rating tools for the sustainability of the selected case study.
- Achievement of green rating credits/level.
- Comparative analysis of sustainability assessment tools to understand mechanisms and inputs of green ratings".

1.4 Scope of Work

Sustainability assessment of a building by selecting green building rating tools. These are:

- LEED
- BREEAM
- CASBEE
- Green Star
- BEAM Plus

Comparative analysis of rating tools and comparison between rating tools and triple bottom line of sustainability. select most suitable rating tool for our region.

1.5 Limitations of Work

Following are the limitations of the research work

- The study is limited to a five stories residential building.
- Five rating systems are selected.
- Energy analysis is out of the scope of the study.

1.6 Brief Methodology

The methodology of research work is shown in figure 1.1. Firstly, a critical literature review is done for the identification of the research gap. A case study and rating tools have been selected. Rating tools are applied and comparative analysis is done. After analysis, based on results, conclusions, and recommendations are performed.

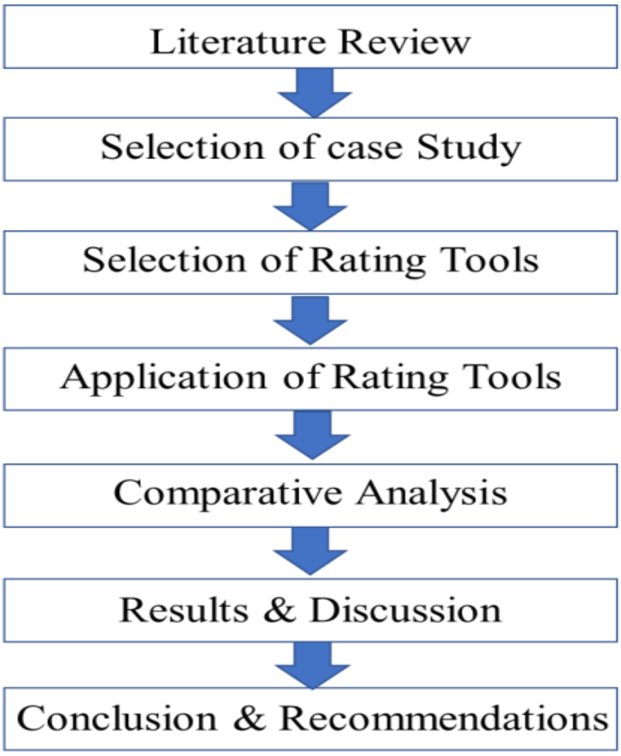

Figure 1.1: Brief Methodology of the Research Work

1.7 Thesis Outline

This research consists of five chapters. These includes:

Chapter 01: This chapter described, the overview, and background of the research, research motivation and problem statement, objective and scope of work, limitation of the study, and brief methodology along with the thesis outline described concisely.

Chapter 02: This chapter explains a comprehensive and critical literature review about the overview, aspects of sustainability, and concept of green building in the construction sector, features of green building rating tools along with sustainability assessment, and their comparison. The research gap is also explained.

Chapter 03: A detailed methodology of research work is explained in this chapter. The selection and adoption of tools, techniques, and methods for the analysis of data have been identified.

Chapter 04: This chapter describes the results obtained and also covers the discussion on the achieved results.

Chapter 05: This chapter covers the conclusion of the research and future recommendations.

Chapter 2

Literature Review

2.1 Background

The construction industry contributes a vital role towards the needs of the community and for the improvement of quality of life [7], and economic development of a country construction industry contributes a lot [8]. However, it has been severely criticized for carbon release, degradation of the environment, and global warming [9], usage of natural resources, and consumption of energy [10]. Also, for the preparation of construction materials, 10% of the total global energy supply is utilized by the building sector of the construction industry [11]. In developed countries construction waste and demolitions generated by buildings are responsible for 40% of solid waste [12]. Additionally, the construction sector is the main energy consumer, accounting for 40-50% of the total worldwide energy consumption and greenhouse gas emissions [13]. According to the IPCC report (2017), there is an increase in global warming of 1.5-2C. Energy consumption plays an important role in this regard. To reduce the energy consumption in buildings, the energy-efficient design is very vital. Due to the challenging conditions of climate change and increasing global warming, the perception of sustainability needs to be entrenched in all human activities [14]. Sustainability can be embedded in the construction sector through green buildings. Based on ecological principles, green buildings are constructed and accounts for the operative use of natural resources without negotiating vigorous facilities [15].

2.2 Sustainability

Sustainability is an ability to live in a constant state, meeting the needs of the present generation, without using the assets of the future generation to overcome future difficulties [16]. Sustainability has three dimensions environmental, social, and economic [16]. Environmental sustainability refers to the sustainability of natural resources and the environment [17]. Social sustainability is responsible for the communal welfare of living and workers [19]. Lastly, economic sustainability refers to the performance of construction costs, which include initial direct cost and indirect costs of the project and operating costs over a lifetime of the project [20].

2.2.1 Environmental Sustainability

Environmental sustainability means the continuing feasibility of a natural environment that contributes to enduring development by taking resources for supply and emissions [17]. It has recognized the environmental aspect of sustainability as a demonetization of economic action, a reduction in material resources can minimize stress on natural schemes and extend environmental services to the economy [18]. Energy consumption is recognized as a standard concerning water use, greenhouse gas emissions, the use of sustainable materials, low health-hazardous materials, renewable energy use, and environmental measures of sustainability.

2.2.2 Social Sustainability

Social sustainability is associated with the comfort of any individual directly or indirectly affected by developmental efforts [19]. Therefore, the social aspect is related to human emotions such as safety, comfort security and skills, and human contributions such as perception, motivation, and health [17]. The purpose of social sustainability is to equally protect the socio-cultural and spiritual needs of people with stability in human morality, relations, and organizations [17]. Said, et al. [19] argued that environmental sustainability or management is essential to social sustainability, although it is fundamentally important to the life support system [17]. The social dimension of sustainability includes a common interest in the project, standards for worker safety, leadership and knowledge management, training of resident workers and workers during construction, operation, maintenance, and demolition [20].

2.2.3 Economic Sustainability

Direct and indirect cost reduction, operating costs, and the time of construction are known as economic sustainability [20]. Financial well-being is associated with monetary benefits from the construction project to give benefit to the public, contractor, customer, and government [21]. Therefore, financial or economic sustainability can be seen as specifying construction costs, operating costs, operating and restoration costs, and market potential.

2.3 Sustainable Development

According to USGBC (2016), sustainable development refers to generating environmentally responsible, healthy, unbiased, and gainful spaces. This definition is reflected in all-natural, human, and economic systems. Almost all shared features of sustainable development are concerned with environmental, economic, and social considerations [17]. Sustainable development goals are the threshold to achieve sustainability. Due to the rapid carbon emissions from the construction industry, sustainable development goals should be kept in mind during the design and operation phase of construction [17]. Out of seventeen goals of sustainable development, sustainable and smart cities, climate action and renewable energy can be achieved to a certain level through green construction in the construction industry.

FIGURE 2.1: Sustainable Development Goals [24]

2.4 Green Building and Construction Sector

Environmental degradation and energy use are the two main challenges faced by the construction sector. Green design can help builders to cater to these challenges, they not only have a good effect on the environment and public health, but it can also minimize operating costs, improve market and organizational productivity, increase productivity, and help to create a sustainable society [24]. There is a lot of challenges that sustainable development faces which include increasing city prices, public affairs, low skill levels, an unstable economic environment, and a deteriorating natural environment [25]. Improvements that can be sustained in the state of green buildings are far more than a topic of discussion in the construction zone. The promotion and application of the concept of sustainable construction have been a central theme of modern design [22]. Sustainable buildings present a range of strategies to lessen the harmful impact on energy use, the healthy environment, and human health and comfort [23]. Environmental services are established to identify and assist in the construction, construction operation, maintenance, and rehabilitation and disposal. This needs major cooperation with the technology team, designers, engineers, and customers at all phases of the project.

It has been observed that community awareness and engagement are important for GB expansion [26]. the most important factor for successful GB projects is awareness in the public for ongoing concepts and correlated benefits [26]. Kim et al. [27] proposed a model for assessing the cost influences of using an energy-efficient strategy. By comparing the conventional systems to green building applications, owners can save money to reduce the operating cost of their buildings [27]. Due to the decision making to construct a new GB, it is observed that 30% of energy consumption is reduced and 25% productivity increased [20]. It was found that, in Hong Kong and Singapore, both are considered as developed countries, while the cost of construction per GB may be higher as compared to conventional buildings, but on the other hand original operating cost was less than 10% [20]. There is, however, energy, efficiency, and conservation associated with GB [20]. Dobrovolskien and Tamoinien [20] investigated the usage of GB material e.g. green roof and found environmental paybacks like a significant reduction in air pollution [20]. Kang et al. [29] highlighted that water efficiency, reduced CO2 emissions, and high energy efficiency was considered to be well accepted by the environmental benefits of GB construction. GB project managers should have specific and indirect skills, such as analysis, decision making, and delegation skills. Major areas of information required include cost, communication, claims, information, stakeholders, and financial management. These requirements have been reiterated by [28]. Samari, et al. showed the difference between planning required for regular and GB projects, the latter requiring additional planning efforts due to the complexity and lack of sufficient understanding of the overall GB projects [29]. It is determined that in Malawi major barriers to GB implementation could include a deficiency of resources available to cover the initial cost of a project, potential investment risk, a lack of GB customer demand, and a high final price. Because of this, the benefits of GB cannot be realized without the so-called green population [30].

2.5 Green Building Rating Tools

A rating system is a set of best practices that assess sustainability by incorporating a series of indicators [31]. Environmental assessment methods are considered to be powerful and effective ways to enhance the efficiency of buildings [32]. Sustainability tools are the processes for classifying, predicting, and assessing the impact of various processes on major sustainability aspects [44]. Rating tools have begun to redefine a stable structure for sustainable development [16]. The rating tools offer a means of screening that the structure has succeeded in achieving the level expected to function in several specified ways [5]. The GBRS is gaining worldwide momentum with the wide variations available [33]. Without question, the introduction of green assessment tools has significantly impacted the requirement in the construction industry promoting sustainable construction and subsequently the building's performance. There are many sustainable building programs around the world, which attempt to explore issues affecting the functionality of the building and sometimes, evaluate the building's impact on its surroundings [34]. Fundamentally, all rating systems seem like all having the same to adopt the same method, but all systems are unique to some extent in an assessment process, instruments and scoring, the performance evaluation process, and the final score calculation [35]. Projects certified by such assessment systems are considered to provide improved accommodation, utilized minimum energy and increased the overall value of the project [36]. These are tools for measuring green construction designed to investigate and assess the performance of buildings from planning, construction, operation, and demolitions used in credit terms [37]. Due to the decline in social and economic factors causing environmental problems, rating tools are often criticized [31]. GB assessment tools are designed for building types like residential apartments, hospital buildings, industrial buildings, schools, office buildings, and many other kinds of buildings [38]. New buildings as well as existing buildings are also being tested separately and are being tested on different benches. Therefore, many of these rating systems will emerge over time, including modern technologies, principles, and experience in practice. Due to the climatic conditions and varying requirements across different countries, GBRTs have many assessment methods [39]. Studies investigated that, by the application of assessment tools in buildings, there is a vast decrease in the environmental influence by the buildings and energy can be saved up to 40% on annual use [40]. The green rating assessment tools assess, endorse and improve green practices in the construction area by providing a framework that gives direction and provides an inclusive and inclusive understanding of resilience by testing, research data, and classification [41]. The GBRS informs the public of how sensitive and sounds the environment is, demonstrates the nature of the raw elements, and identifies the standard terms and procedures that have been employed [42]. It is observing that the tools for measuring green construction are described in terms of geographical conditions and climatic situations and these variances are the consequence of a change in the consistency of the concept of resilience in the geographic area [43]. Building rating assessment tools have various main features. The country of respected rating tool, organization, the first version, latest version, and assessment categories are discussed.

2.6 Green Building Assessments

The GB rating assessment is a method of assessment for checking the sustainability considerations in a building i.e. the concern building has sustainability aspects under considerations or not, and the certification is assigned to the respective building after a comprehensive investigation [32]. There is a range of tools for assessing structural stability, including measurement systems, basic LCA tools, technical guidelines, evaluation framework, checklist, and certifications [45]. Therefore, systems for sustainable building certification try to resolve problems that affect the functionality of the building and sometimes evaluate the influence of the building on its structure [34]. Green rating tools provide a means of screening that a structure has succeeded in achieving the desired performance level in

Table 2.1: Overview of Green Building Assessment Tools [36]

GBRT	**BREEAM**	**LEED**	**CASBEE**	**Green Star**	**BEAM-Plus**
Country	UK	US	Japan	Australia	HK
Organizations	BRE	USGBC	JSBC	GBCA	HKGBC
First version	1990	1998	2002	2014	2009
Latest version	2016	2013	2015	2017	2016
Major	Energy	Energy	Indoor	Management	Indoor
Categories	Transport	Material	Environment	Material	Environment
	Water	Indoor	Quality	Emissions	Quality
	Health and	Environmental	Energy	Energy	Innovation
	Well-being	Quality	Efficiency	Land Use	Energy Use
	Waste	Regional	Resource	Transport	Site Aspects
	Pollution	Priority	Efficiency	Water	Water Use
	Land Use and	Water efficiency	On-site	Innovation	Material and Waste
	Ecology	Sustainable Sites	Environment		Aspects
	Management	Innovation		Indoor	
	Innovation	Integrative		Environmental	
		Process			
		Transportation			

several specified ways [5]. Mattoni et al. [43] emphasized that, for the evaluation of the sustainability level of a building by adopting various assessment tools, there is a considerable variation in the final levels due to varying design and scheming techniques. These are various aspects that green buildings need to fix some of them are as follows, purification of greenhouse gases, indoor air pollution, energy use in buildings, water buildup, land use, materials use, waste disposal of the construction phase and operational phase [46].

2.7 Previous Work done by Green Building Assessment Tools

Table 2.2: Previous Work Done by Green Building Assessment Tools

Sr. No.	Authors	Scope	Tool Used	Conclusion/Results
1	(ElSorady and Rizk, 2020)[47]	Assessment of indoor environment quality	LEED v4.1	To enhance indoor environment quality and energy conservation of a building, passive design approaches, and material choice are very crucial.
2	(Illankoon and Lu, 2020)[48]	Cost implications in green buildings to obtain CWM credits	BEAM Plus	a. To obtain CWM related credits, the cost increases from 0.4 to 6% than the normal cost. b. In BEAM Plus "Material Aspect" has only 8% credits which are lowest than all other categories.
3	(Niksefat and Taghizade, 2020)[49]	Criteria selection for building assessment and development of Irans rating system	LEED, BREEAM, Pearl, QSAS, and SEAM AHP technique and Expert-Choice Software	a. Irans rating system (ISBRS) obtained 3 points (8.9%) for the innovation category which has a second-place after BREEAM with (9.1%). b. ISBRS has a cultural aspect with weight 7.1 rather than Pearl and SEAM.
4	(Li et al., 2019)[50]	Cost analysis of green buildings	Green Mark Regression Analysis	a. The average annualizes value of OC, LCC, and CC of sustainable buildings are S$ 130.18 per m2, S$ 222.03 per m2, S$ 91.85 per m2, and respectively. b. LCC and CC will enhance by S$ 25.37 per m2 and CC will increase by S$ 47.81 per m2, for one level increase in GMCS with no effect on OC.

Sr. No.	Authors	Scope	Tool Used	Conclusion/Results
5.	(Al-Qawasmi et al., 2019)[51]	Management aspects and Water efficiency in assessment tools	BEAM Plus, Green Star CASBEE, GSAS, LEED, BREEAM, Pearl, and SB Tool Coverage Analysis Technique	a. After analyzing 11 rating tools by coverage analysis it is noticed that 8 rating systems show a 45% degree of water subsections computed in the CLWC. b. 6 out of 11 assessment tools have high to moderate coverage of water specifications correlated to the eco-friendly pillar in green buildings.
6.	(Suzer, 2018)[52]	correlation between LEED and BREEAM	Criteria based analysis	a. A comprehensive analysis of the criteria of LEED and BREEAM demonstrates that both have 83% common issues/credits. b. In the certification of projects, expectations of BREEAM are higher than LEED, as its discretely addressed credits are sophisticated than LEED.
7.	(Vyas et al., 2019)[53]	Advancement of building assessment tools	Fuzzy and AHP Integrals	a. The proposed framework of assessment comprises of nine components, 34 features, and 68 constraints for the development of a GBRS. b. Government policy and regulation, BIM, public awareness, climatic conditions, and cultural aspects are also considered.
8.	(Zhang et al., 2019)[54]	Assessment of renewable energy in green assessment tools	LEED, Green Mark, HQE standard, ASGB.	Green rating tools generally have geothermal energy, solar energy, and wind energy as renewable energy. b. Only BREEAM secure thermal comfort in passively designed buildings for certifications.

Sr. No.	Authors	Scope	Tool Used	Conclusion/Results
9.	(Doan et al., 2019)[60]	A comparison between GBRS	Green Star, BREEAM, CASBEE, LEED	a. BREEAM rating tools are one of the strongest assessment tools in which not only Environmental aspects and Social aspects are thoroughly assessed but the Economy also considered. b. Green Star considered the weakest rating tool because its major considerations are about environmental issues. While Social aspects are critically assessed by LEED, and a well-proportioned rating tool is CASBEE in which all sustainability aspects are assessed.
10.	(Atanda and ztrk, 2018)[41]	Evaluation of social criteria in sustainable building rating systems	BREEAM, CASBEE, GSAS, SBAT, SB Tool, Green Star, LEED	a. Social criteria have the highest priority in weight points (36.7%) in SBAT. b. CASBEE and LEED significantly having the minimum assigned a percentage of social criteria in CASBEE and LEED are at least one 6% and 11% respectively.
11.	(Ding et al., 2018)[55]	Identification of barriers in the certification of green buildings	LEED, BREEAM, Green Star	a. Out of the total cost of the project only 0.27% cost is served as a decorative cost for construction, which expresses less than 2%.
12.	(Mattoni et al., 2018)[43]	Differences among GBRTs	LEED, BREEAM, CASBEE, Green Star, ITACA	a. CASBEE gives the highest importance to the Comfort and safety area, but other systems give priority to Energy.

Sr. No.	Authors	Scope	Tool Used	Conclusion/Results
13.	(Huo et al., 2017)[39]	Site planning and design among GBRTs	LEED, ASGB, BREEAM, BEAM Plus, GM	The SPD credits in ASGB, LEED, and BREEAM are 23%, 23.4%, and 13.3% respectively. BEAM Plus assigns 25% which is the highest one and the lowest credits allocated by which is 7.44%.
14.	(Diaz-Sarachaga et al., 2017)[61]	Development of a new SIRSDEC	Sustainability assessment with integrated value model and AHP	SIRSDEC highlights the pillars of sustainability by focuses on the social aspect and economic aspect with management as the relation between the three aspects of sustainability.
15.	(Uur and Leblebici, 2107)[56]	Examination of LEED in terms of construction cost	LEED	To achieve the gold and platinum certification level in building respectively, the extra construction cost was originated to be 7.43% and 9.43%, in total cost the share of the soft cost was quantified to be 0.84% and 1.31%, decrease in consumption cost of annual energy was found as 31% and 40%, also extra construction costs payback period was intended to be 0.41 and 2.56 years.
16.	(Bisegna et al., 2016)[57]	Impact of insulating material on GBRTs	LEED, ITACA	Credit points of two categories: energy and material/resources can be increased by using wood fiber".
17.	(Wu et al., 2016)[58]	Investigation of point allocation pattern of certified buildings	LEED v2.2	a. Enhancement in the energy category is essential for LEED v2.2 Certified and Silver projects. b. Substantial enhancement in indoor environmental quality is also necessary for LEED v2.2 Gold Certified projects.

2.8 Major Concerns Evaluation Using GBRTs

Green building assessment tools have many measures for the evaluation of sustainable buildings. Different rating tools have different criteria and categories for assessment. But mostly rating tools have almost the same norms for green building rating assessment. These are the following criteria for assessment.

2.8.1 Indoor Environment Quality

For the evaluation of GBDFs as its straight link to the occupants' health, productivity level, and satisfaction level, indoor environmental quality is considered [62]. Sage-Lauck and Sailor [63] studied the influence of integrating phase-changing materials into the envelope of building (exterior walls, foundation slab, roof, windows, and partition walls) to enhance the thermal well-being in a residential apartment. 50%60% of overheated zone hours can be minimized by using this modern technology [63]. Practices that save energy might have negative impacts on the indoor atmospheric quality and energy demand and its effects can be facilitated by a sensor-based management process [64].

2.8.2 Energy Use

For the minimization of inclusive energy demands in the building, the optimization of the energy utilization of an HVAC system can be done by operation of an adaptive model-free hybrid metaheuristic algorithm for having the govern overheating and cooling phenomenon [65]. Web-based (BIM) system can be incorporated in the monitoring process of the energy of a building to permit the operator to remotely monitor and acquire the energy-related information of the building, in this way the energy-saving is 12.10% of total energy consumption [66]. James and Weeratunge [67] presented an energy monitoring system that is low cost and mechanically control and monitor electronic home appliances and this system has a major consequence on energy utilization. Al-Ghamdi and Bilec [68] investigated the potential energy creation structures in the construction site of buildings by exploring the several options of wind energy and solar energy.

2.8.3 Water Use

Das and Moulick [69] investigated the huge water usage impact of building and explore the several modern technologies by presenting important water-saving designs in green buildings. Schantz et al. [70] proposed a water monitoring system based on sensors, these sensors can help the water heaters, vertical water pipes as well as bottom water pipes to determine any leakage during water distribution. Lee and Balbin [71] evaluated how long-term water could be saved by using water-efficient equipment. Campisano and Modica [72] investigated the benefits of rainwater harvesting tanks in green buildings on water usage.

2.8.4 Material Use

Zabalza et al. [73] compared three types of eco-materials with the construction material used in common practice to check environmental impact by them and for the improvement of material, the selection set a baseline. Densley et al. [74] utilized three insulated materials in exterior walls for the improvement of thermal efficiency and to determine the effect on the environment. Azari [75] conducted an analysis based on the building envelope materials such as windows, roof, exterior walls, the floor for the evaluation of environmental and energetic influences. Worrell and Gutowski [76] concluded that a 50% reduction in the material can be achieved by reuse and recycling approaches, lightweight material strategies, and by increasing the lifetime of the materials used in roofs, walls, and floors of the building. Rincn et al. [77] proposed a new strategy as a green roof to insulated conventional roofs and determine momentous environmental enhancements by reducing 14.8% cooling energy consumption.

2.8.5 Construction Waste and Pollution

To improve the green practices in construction and environmental load in the whole building life cycle, construction waste management is very essential. Wang and Tam [78] identified in their research that, critical factors such as minimize the floor and internal wall thickness can assist in the reduction of construction waste. Breen et al. [79] explored models and various types of air exchange rate systems for improvement in air pollution assessment. Schroer and Hlker [80] proposed several light pollution improvement strategies such as smart lighting system and installing shades. Spitschan et al. [81] studied the daylighting effect on outdoor illumination.

2.8.6 Land Use

The land use is an important parameter in green building practices to save the earth and preserve natural resources. Shafique [82] introduced a new concept of a green-blue roof, which is an advancement in the green roof concept to mitigate the heat island effect by allowing the storage of rainfall. This modern technology can minimize the temperature of the roof surface due to the evaporation by 5C to 9C, by utilization of deposited rainwater. Fudaa et al. [83] explored the evaporation system which is planned concerning the local weather data by utilization of building roof for the management of rainwater.

2.9 Comparison of Green Building Rating Tools

Tools for measuring green construction can be compared in many ways such as categories, sub-categories, indicators, and many other factors. BREEAM imposes higher levels of property management compared to LEED and Green Star. The SB tool, CASBEE, and LEED management are managed in other ways [84]. LEED and BREEAM calculate equal energy and transport scores while Green Star falls behind. Depending on health and wellness issues, BREEAM also outperforms other schemes [85]. A smaller amount of consideration is given by LEED, Green Star, and BREEAM to quality of service as compared to CASBEE and SB tool. Cultural, material, and socio-economic factors are considered to be the SB Tool, on the other hand, Green Star, LEED, CASBEE, and BREEAM deficit the categories specified in their standards [84]. BEAM Plus weighs 8% of the material factor credits, which is very low compared to the rest of the key processes, while this practice is diverse from LEED where points share the same weight [48]. CASBEE promotes the use of composite materials in concrete, secondly, BREEAM provides loans for both integrated and secondary, thirdly Green Star mentions the usage of other surfaces made up of other fine aggregates in concrete [86]. CASBEE deliberates the maximum number of 94 criteria, on the other hand, ITACA incorporates a few aspects of rigidity [87]. Energy needs can be categories into three major groups such as the reduction in energy demand, renewable energy consumption, and environment-related profits. LEED, Green Star, and BREEAM focus on the assessment of energy efficiency, while China's energy efficiency assessment system and Green Mark emphasizes the use of energy-saving measures [87]. The proportion of credits assigned to EE consideration in the three basic green rating programs available is approximately (7%), (8%) and (11%) by Green Star, LEED, and BREEAM respectively [88]. The highest rating of Green Star is less conservative as compared to the LEED platinum rating and is approximately equal to the BREEAM's highest ratings [85].

2.10 Triple Bottom Line of Sustainability and Rating Tools

Green building assessment tools are not equally entertaining all aspects of sustainability. Even though the fundamental three pillars of sustainability (environmental, social and economic) were considered to be equally significant, these three pillars are not equally focused on rating tools [43]. Rating systems mainly emphasize on the environmental aspect, the social aspect is also considered up to some extent but the economic aspect is negligible [55]. Only LEED and BREEAM consider economic aspects in credit points allocation [60]. Triple Bottom Line of sustainability should be equally focused by rating tools for sustainability assessment.

Table 2.3: Triple Bottom Line and GBRTs [17]

Green building Rating Systems	**Environmental Sustainability %**	**Social Sustainability %**	**Economic Sustainability %**	**Others%**
LEED	74.59	18.03	0.82	6.56
BREEAM	74.62	16.15	2.31	6.92
CASBEE	25.00	17.95	0.00	57.05
BEAM Plus	56.43	29.29	0.00	14.29
Green Star	75.00	18.00	0.00	7.00

2.11 Research Gap Analysis

It has been seen that most of the critical literature review is about the individual categories assessment of green building rating tools. The sustainability assessment of the building by application of five green building assessment tools and comparative analysis of results by all rating systems has not investigated in detail. Most of the work has investigated the comparison of rating tools by credit criteria but not proceeded further studies. In current research work, five world-famous rating systems have been chosen and applied on a case study for sustainability assessment and comparison of all rating systems about sustainability aspects. Results will show the level of sustainability of the concern building, after the application of rating systems. The green building concept is very rare in our country. It should be introduced in all aspects of the construction sector. This study, which assesses the sustainability of the building, will help the industry in a new way to adopt these rating systems in their projects for sustainable endeavors.

Chapter 3

Research Methodology

This chapter explains the procedure of research work and describes the methods and techniques selected for the completion of the research objectives. A critical and comprehensive literature review was conducted. The required primary data was obtained from the concerned organization and secondary data was obtained through site visits. Figure 3.1 defines a comprehensive summary of the flow of research methodology in graphical format.

Green building rating tools were selected after the preliminary study. Green rating assessment was performed on the selected case study and credits/ points were awarded leads to the sustainability threshold. Based on results obtained after assessment a detailed comparison of rating tools was conducted. The figure shows the details of the methodology adopted in the research work.

3.1 Preliminary Study

A preliminary study was conducted to obtain the fundamental knowledge of the research topic. Problem statements and objectives of the research topic were identified after the preliminary study.

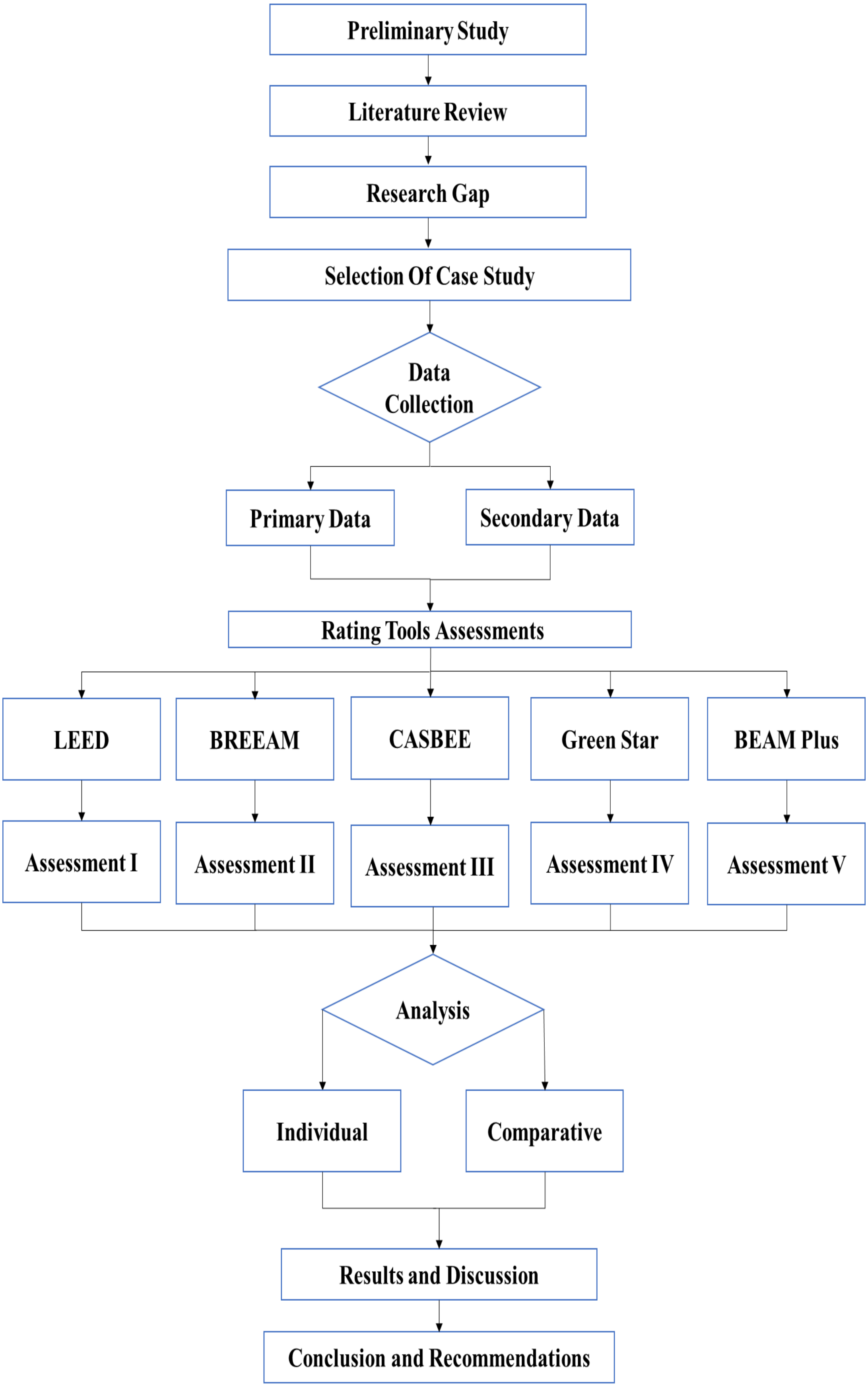

FIGURE 3.1: Flow Chart of the Research Methodology

3.2 Data Collection

In this research, the data comprised of two types. One is primary data and the other is secondary data.

3.2.1 Primary Data

This data is necessary for the assessment of the many categories of the rating systems. Primary data is collected from the concerned organization.

3.2.2 Secondary Data

This data is collected by a survey at the concerned location during site visits. Secondary data is also required for the assessment of certain categories of each rating system. The type of data and source of data are shown in Table 3.1.

Table 3.1: Data type and Source of Data Used in Current Research

Sr. No.	Data Type	Description	Source of Data
1	Primary Data	i. BOQ	Concern organization
		ii. 2D and 3D drawings	Concern organization
		iii. Rating systems Manuals	[89],[90],[91],[92] and [93]
2	Secondary Data	On-Site Assessment Data	Site Visits

3.3 Case Study

A residential building was selected for the sustainability assessment to explore sustainability in the construction zone. The building comprises five floors with the ground floor with an area of 5423.19 square feet. It is a frame structure. The 2D drawings, 3D drawings, bill of quantities were collected from the concerned organization. The other data is collected from the on-site assessment of the building, questionnaire survey, and interviews with clients and contractors. These tools were selected among most advanced rating tools adopted by most advanced countries and followed by many other countries also. In addition, the data access of the selected rating tools was free. The manuals were easy to understandable. Since the assessment required a comprehensive access to the building and its systems. So, the building was selected on basis of this vital approach as it facilitated both requirements for our assessment. The location of the residential building is the capital city of Pakistan as shown in figure 3.2.

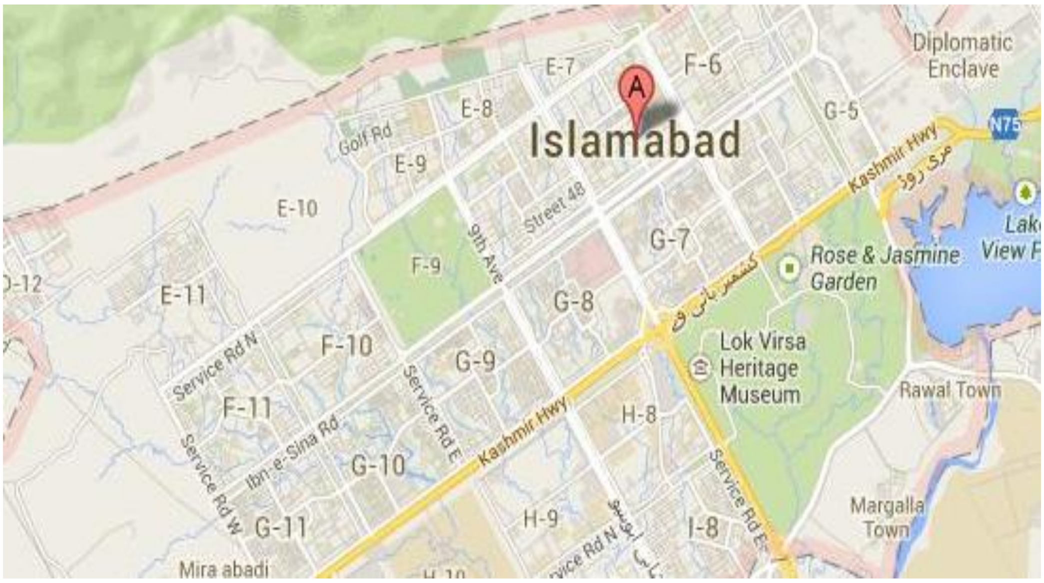

FIGURE 3.2: Location of the Case Study

3.4 Rating Tools Assessment

Five rating assessment tools were selected for the rating assessment of a residential building. These GBRTs were selected based on their relevance (the desired scope of work assessed by these rating tools or not), applicability (whether these rating tools can be applied on a concern case study or not), measurement (whether these tools are suitable for the assessment of important parameters in a building that relate to sustainability or not). These include LEED, BREEAM, CASBEE, Green Star, and BEAM Plus. Based on categories and sub-categories assessment a rating is awarded by the GBRT.

3.5 Rating Tools Assessment Categories

At the building scale, green building rating tools have categories and sub-categories. In the selected rating tool for current research work, each rating tool has specific categories for assessment. Mostly rating tools have some common categories like energy, water efficiency, indoor environmental quality, etc. These categories have some credit points, some have more and some have less, which shows the priority of category according to concern rating tool. The categories and sub-categories of rating tools are explained in the later section.

3.5.1 Categories of LEED

LEED is comprising of a multitude of criteria (based on the requirements, some are prerequisites for the rating assessment). These are divided into eight main categories and further sub-categories. Each assessment category (except prerequisite) is accompanied by many available points, which are achieved based on the performance level of the concern case study. Due to the location of the building (e.g., country), the number of obtainable credits in each category differs and portrays its rank. All the credits are summed up that a building earned for awarding the ranking to the building. The main categories and assessment credits of LEED are shown in table 3.2.

Table 3.2: Main Categories and Assessment Credits of LEED [89]

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

3.5.2 Categories of BREEAM

BREEAM comprising of several assessment measures, that are arranged into assessment issues. In BREEAM assessment issues are categorized into nine assessment parts and a further one additional category Innovation is also available for credits. Each criterion has a specific number of obtainable assessment credits. Based on the degree up to which the requirements of criteria are met, these points are awarded. At this stage, one thing should be noted that in each specific criteria framework there should be minimum performance limits that are required to progress further. So, essential environmental assessment problems are not ignored. The percentages of all categories added that will give a final percentage, innovation section is also summed up to the final score and the building under concern will get a rating classification. The main categories and percentages of credits are shown in table 3.3.

Table 3.3: Main Categories and Percentages of Assessment Credits of BREEAM [90]

Category	**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

3.5.3 Categories of CASBEE

For the assessment of the performance of a building concerning the environment, CASBEE covers the many set of criteria. All assessment criteria are further divided into sub-categories, which cover the more fundamental environmental concerns.

Table 3.4: Main Assessment Categories of CASBEE [91]

Category	Representation
Environment Quality of building	Q
Indoor Environment Quality	Q1
Quality of Service	Q2
Outdoor Environment Quality	Q3
Environmental Load Reduction of Building	LR
Energy Use	LR1
Resource and Materials Use	LR2
Off-site Environment Quality	LR3

All these categories and sub-categories are the constituent part of the main assessment factors i.e. (environmental quality of building) represented by Q or (an environmental load of a building) represented by LR. Five level assessment scale is a standard that is set for the assessment of all the criteria. The performance level of the concern building is determined by the score achieved against each category. The final score of all categories is, in fact, the values of the Q and LR factors. So, the values of Q and LR are utilized for the calculation of the BEE and the building is classified to a rank. The main assessment categories of CASBEE are shown in table 3.4.

3.5.4 Categories of Green Star

Green Star comprises of various sets of assessment criteria. Based on the performance, the building achieves a level in such criteria. Nine performance issues are assessed in the form of categories, these categories are further divided into sub-categories for covering all important environmental issues. All categories have some credits for assessment. Some categories have a huge difference in credits from other categories due to major concerns on the environment.

TABLE 3.5: Main Assessment Categories and Available Credits of Green Star [92]

Category	**Points Available**
Land Use and Ecology	6
Indoor Environment Quality	17
Materials	14
Transportation Facilities	10
Innovation	10
Energy	22
Emissions	5
Management Aspects	14
Water	12
Total	110

The score of all categories is summed up and a level is achieved. The final score presents the ranking of the building. The main assessment categories of Green Star are shown in table 3.5.

3.5.5 Categories of BEAM Plus

BEAM Plus consists of six main assessment categories. These six categories have further sub-categories for building assessment. Some categories have certain pre-requisite for fundamental issues. For proceeding in assessment, these pre-requisites must be met. Some bonus credits are also available in some categories. All credits of respective categories are added and a total score is calculated. Based on the total score, the building achieves a certification rank. Main assessment categories of BEAM Plus are shown in table 3.6.

Table 3.6: Main Assessment Categories and Available Credits of BEAM Plus [93]

Category	**Points Available**
Water Use	24
Site Conditions	22
Materials and Waste Aspects	17
Indoor Environment Quality	26
Management Aspects	23
Energy Use	39
Innovation	10
Total	161

3.6 Rating Assessment Criteria

Each green building rating tool has some criteria for assessment. If a building follows the criteria of the respective rating system then awarded certification by that rating system. The following are the criteria of the selected GBRTs.

3.6.1 Rating Criteria of LEED

LEED is a famous tool of the US used for rating assessment of buildings. After the application of LEED to concern building, credit points are awarded by LEED that show the sustainability level of the building. Here LEED [89] version is chosen for assessment. A minimum of 27 points is necessary to get the certification by LEED. The assessment criteria of LEED [89] are shown in table 3.7.

TABLE 3.7: Points Distribution Criteria by LEED [89]

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

3.6.2 Rating Criteria of BREEAM

BREEAM is a sustainability rating assessment tool in the UK. The sustainability level of the building is achieved after the assessment of the building. BREEAM ratings are determined by achieving a set percentage of threshold points. BREEAM [90] is used for concern building assessment. If our building gets below 10% of the threshold, then the building is unclassified. So, a minimum of 10% of the score is required for acceptability. The assessment criteria of BREEAM [90] are shown in table 3.8.

TABLE 3.8: Points Distribution Criteria by BREEAM [90]

Rating	**Score %**	**Star Rating**
Outstanding	Less than or equal to 85	⋆ ⋆ ⋆ ⋆ ⋆ ⋆
Excellent	Less than or equal to 70 to less than 85	⋆ ⋆ ⋆ ⋆ ⋆
Very Good	Less than or equal to 55 to less than 70	⋆ ⋆ ⋆ ⋆
Good	Less than or equal to 40 to less than 55	⋆ ⋆ ⋆
Pass	Less than or equal to 25 to less than 40	⋆ ⋆
Acceptable	Less than or equal to 10 to less than 25	⋆
Unclassified	Less than 10	—

3.6.3 Rating Criteria of CASBEE

CASBEE is a sustainability rating assessment tool for Japan. An inclusive rating assessment of the environmental performance of the building is evaluated by CASBEE. CASBEE assessment is ranked in the form of grades. BEE values are calculated for grade assessment. BEE is calculated using the following equations

$BEE = \frac{EnvironmentalQualityofBuilding(Q)}{EnvironmentalLoadofBuilding(L)}$

Whereas, Environmental Quality of Building (Q) = $\frac{\Sigma(Q1,Q2,Q3)}{3}$

Environmental Load of Building (L) = $\frac{\Sigma(LR1,LR2,LR3)}{3}$

CASBEE [91] is used for a concern case study. The assessment criteria of CASBEE [91] are shown in table 3.9.

TABLE 3.9: Grading Criteria by CASBEE [91]

Grades	Assessment	BEE value	Expression
'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-'	Fairy Poor	0.5-1.0	⋆ ⋆
'C'	Poor	< 0.5	⋆

3.6.4 Rating Criteria of Green Star

Green Star rating tool is of many countries like NZ, SA, and Australia for assessment. For the current research, the Green Star rating system of Australia is used for rating assessment. A rating scale for the certification is in the form of star ratings awarded. Green Star [92] is used for the current research. The assessment criteria of Green Star [92] are shown in table 3.10.

TABLE 3.10: Ranking Scale by Green Star [92]

Outcome	Rating	% of available points
Only Assessed	—	Less than 10
Minimum Performance	⋆	10-19
Average Performance	⋆ ⋆	20-29
Good Performance	⋆ ⋆ ⋆	30-44
Best Performance	⋆ ⋆ ⋆ ⋆	45-59
Excellence Performance	⋆ ⋆ ⋆ ⋆ ⋆	60-74
Leadership	⋆ ⋆ ⋆ ⋆ ⋆ ⋆	75+

3.6.5 Rating Criteria of BEAM PLUS

BEAM Plus rating tool used by the HK for assessment.

Table 3.11: Ranking Grades by BEAM Plus [93]

Rank	Overall Score
Platinum Certified	75
Gold Certified	65
Silver Certified	55
Bronze Certified	40

The certification of buildings that are assessed by the BEAM Plus is in the form of raking grades. BEAM Plus [93] is used for assessment. The assessment criteria of BEAM Plus [93] are shown in table 3.11.

3.7 Sustainability Rating Assessment

Sustainability assessment of a building is to know about the environmental friendliness of a building. The sustainability assessment can be done in many ways, but in the current research, the assessment of a case study is done by applying rating systems. All main categories (management, water efficiency, sustainable sites, energy efficiency, transportation, Innovation, material aspects, etc.) and sub-categories of the selected rating tools are assessed one by one. The assessment is performed by the analysis of data of respective categories, site surveys. Based on the scores of the categories after assessment, the rating will be awarded to the case study by each rating tool. The ranking by each rating tool is the reflection of the sustainability level of the concern case study.

3.8 Comparative Analysis

After the application of all selected rating tools to the case study, individual analysis has been completed. A detailed comparative analysis has been done on the scoring of rating tools, to know about the main focused categories and least focused categories of rating tools. Comparison of certifications achieved by different rating tools. Mainly to determine that the case study is more sustainable by which rating tool. A comparison of the triple bottom line of sustainability and rating tool is also conducted for the determination of environmental, social, and economic percentages of sustainability.

3.9 Results and Discussion

In the results and discussion section, all the findings of the research have investigated and interpreted. Based on the findings, a comparative analysis was made to elaborate on the results. Discussion on the obtained results explores the new findings of the research work.

3.10 Conclusion and Recommendations

In the section of conclusion and recommendations, conclusions were drawn after the analysis of whole research. Based on conclusions, recommendations are made for future research.

Chapter 4

Results and Discussions

This chapter details the results of the current research and its discussion. A sustainability assessment of the selected case study has been performed by implementing five rating assessment tools.

Assessments have been made by all selected tools for the concerned case study. A detailed comparative analysis of all selected rating tools has been performed. This chapter has been explained in two phases. Phase one deals with the individual analysis and phase two deals with comparative analysis.

4.1 Sustainability Rating Assessment by LEED

Sustainability assessment by LEED of the concern case study is done by a detailed assessment of all including nine categories. Each category has certain specifications to assess in the building that relates to sustainability.

4.1.1 Regional Priority

Regional priority deals with public health, local environmental, and social equity priorities in the concern region. Based upon the geographical conditions and the location of the concern case study (1) credit is awarded to the residential building out of (4) credits. The reason behind for awarding (1) credit is the lack of health priorities as there is no hospital in nearby vicinity to the concern case study.

4.1.2 Location and Transport

The location and transportation category deals with the transportation pattern of the occupants. The purpose of this category is to enhance sustainable transportation. The main purpose of this category is to minimize the usage of personal vehicles for a reduction in pollution. The assessment criteria for this category are shown in table 4.1.

TABLE 4.1: Assessment Criteria of Transportation

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

The total no. of occupants in this selected residential building is sixty of eleven families. A survey was conducted to gather information about the transportation patterns of the occupants. The following is the data obtained after the survey shown in table 4.2.

55% of the occupants use alternative means rather than personal vehicles or conventional automobiles. Based upon the results (12) credits out of (15) credits

Table 4.2: No. of Occupants and their Transportation Patterns

No. of Occupants	Transportation Pattern
35%	Biking or Walking
6%	Rideshares
14%	Public transport
45%	Personal vehicle

earned by this category. In this category, the building attained (80%) of the points against the standard. The questionnaire of the survey is attached as Annexure A.

4.1.3 Material Resources

The material resources category emphasizes reducing the embodied energy and impacts by materials during all phases of construction. The assessment criteria for this category are shown in table 4.3.

Table 4.3: Assessment Criteria of Material Resources

Materials and Resources Credits	Points available	Points Achieved
Ongoing Purchasing and Waste Policy	Required	Available
Maintenance and Renovations Policy	Required	Available
Purchasing- Ongoing and Lamps	2	0.5
Purchasing- Facility Maintenance and Renovation	2	1
Solid Waste Management- Ongoing, maintenance and renovation	4	2
Total	8	3.5

This category has a total (8) credits. There are two prerequisites under this category: material waste policy and renovation policy. The case study meets the prerequisites. This category has further subdivisions like ongoing and lamp purchasing (2), maintenance materials purchasing (2), ongoing, and maintenance of solid waste management (4). By the detailed interaction with the contractor and based on specifications of materials in BOQ, ongoing and lamp purchasing earned (0.5) credits, maintenance material purchasing earned (1) credit. There is no specific materials recycling process so, this criterion obtained only (2) credit.

FIGURE 4.1: Percentage Contribution in Materials and Resources

The total credit obtained under this category is (3.5). under this aspect, the building is (43.75%) efficient. The percentages of contributors in material and resource categories are shown in figure 4.1.

4.1.4 Innovation

Innovation category concerns with any other green or sustainable feature in the building other than the standards of the rating system. As per the detailed investigation of primary and secondary data, no innovation was observed in the selected case study other than LEED criteria. Also, there was no LEED professional associated with this case study. So, out of (6) no credit earned by this category.

4.1.5 Water Efficiency

Water efficiency deals with the smarter usage of inside and outside water. It also focuses on the utilization of greywater, recycling of water, and water-efficient devices in the building. The assessment criteria for this category are shown in the table in table 4.4.

Table 4.4: Assessment Criteria of Water Efficiency

Water Efficiency Credits	**Credits Available**	**Credits Achieved**
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

This category has two prerequisites about water savings one is reducing the indoor water usage and the other is water metering. The first prerequisite meets the standard of 1.6gpf for toilets and 1gpf for urinal purposes. The second prerequisite also completed as the water meters are installed for potable water measurement in concern residential building. The indoor water usage reduction earns (2) credits after a detailed investigation of plumbing drawings in which fixtures are observed.

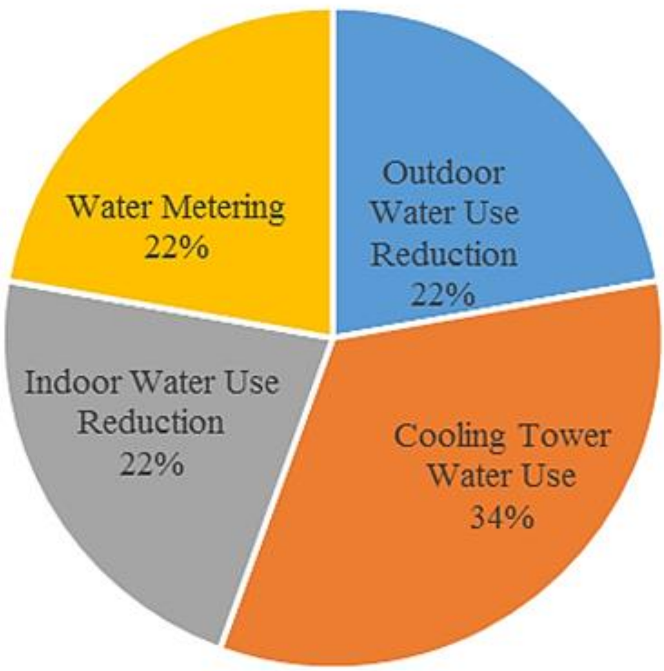

Figure 4.2: Percentage Contribution in Water Efficiency

Outdoor water usage reduction earns (2) credits as there is no extra vegetation outside the building. There is no combined cooling system in the building, no water usage for this category so this earned (3) credits. Water meter is installed to measure the water consumption so, (1) credit earned. Only (9) credit earned by this category out of (12). Considering this aspect, the building is (75%) efficient. The percentage contribution to water efficiency is shown in figure 4.2.

4.1.6 Indoor Environmental Quality

Indoor environment quality relates to the occupants health and wellbeing including thermal comfort, acoustic conditions, interior lighting, and quality views. The assessment criteria for this category are shown in table 4.5.

Table 4.5: Assessment Criteria of Indoor Environment Quality

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

There are three prerequisites in this category. The first one is the good indoor air quality; this meets the standards as more than 4% is the window area compared to the total floor area of a room. Second is about the smoke-controlled environment, this also meets the standard as smoke prohibited signage is available in the building and there is restriction available not to smoke 7 meters within the building area. The third is the cleaning policy which also meets. Management program of indoor air quality is available but during on-site, it is noted that there is no implementation of this program so, only (1) credit earned. Strategies for the improvements in internal air quality also there so, (1) credit earned. For thermal comfort only strategy is available is air conditioning (1) credit earned. Internal lighting earns only (1) credits as according to standard four strategies must be followed but the case study has only two strategies. The daylight is measured in the building with the help of lux meter and the value is 157 lux and the value is taken from 2.5ft above the floor level, (2) credits earned. The case study has the window in every 50% of the occupied space and windows have a clear view of sky and movement, (2) credits earned.

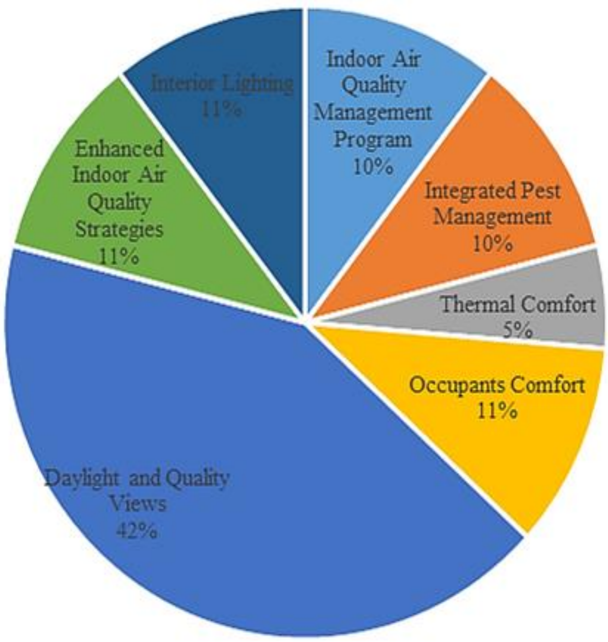

Figure 4.3: Percentage Contribution in Indoor Environment Quality

There are no green cleaning products, equipment, and procedures in practice, zero credits earned. For pest management, not a certain procedure available only (1) credit earned. occupants are comfortable from the aspects mentioned in this category (1) credit earned. Total (9.5) credits earned in this category. Considering this aspect, the building is (55.8%) efficient. The percentage contribution in indoor environment quality is illustrated in figure 4.3.

4.1.7 Sustainable Sites

Sustainable sites refer to ensure that the natural environment has importance throughout the building life. The outdoor environment of the building should also give importance to the indoor environment. The assessment criteria for this category are shown in table 4.6.

Table 4.6: Assessment Criteria of Sustainable Sites

Sustainable Sites credits	**Credits Available**	**Credits Achieved**
Site Management Policy	Required	Available
Site Management and improvement plan	2	1
Rainwater Management	3	0
Light Pollution Reduction	1	0
Site Development-Protect or Restore Habitat	2	0
Heat Island Reduction	2	2
Total	10	3

There is one prerequisite for this category about site management policy, the case study has the prerequisite. For habitat restoration there is no vegetation in the building area, so, zero credit earned.

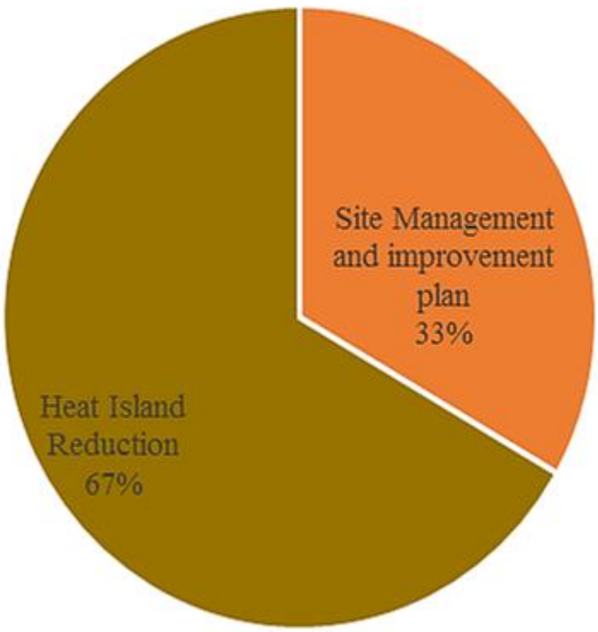

Figure 4.4: Percentage Contribution in Sustainable Sites

As per the drawings, there is no rainwater storage tank in the building to store rainwater so, no credit earned under this sub-category. In reducing heat island more than 50% of the parking space is undercover (2) credit earned. For reducing the light pollution at night there is not strategy available on site so, zero credit earned. Site management and improvement earned (1) credit not completely followed but some practices are available for site management and improvement. Total (1) credits earned under this category. Considering the assessment of sustainable sites, the building is (30%) efficient. The percentage contribution to a sustainable site is illustrated in figure 4.4.

4.1.8 Energy and Atmosphere

This category deals with the energy consumption pattern of the building along with energy analysis, energy efficiency, and optimization of energy. The main purpose of this category is to design buildings in such a way to use minimum energy and use renewable energy sources. The assessment criteria for this category are shown in table 4.7.

This category has four prerequisites the case study has all prerequisites directly or indirectly. Contractors confirmed that the commissioning analysis and improvement of energy in the building both are applied to the case study before the operation, (4) credits earned. During the assessment, it is noted that there is no ongoing commissioning no credit earned. There is no energy optimization of the selected case study, energy usage is similar to the conventional buildings with no improvement in the concern building, no credit earned. Each family has its energy meter and there is access to all residents to see the consumable energy data, (2) credits earned. Solar panels and energy storage batteries are available in the building to reduce peak demand, (3) credits earned. There is no refrigerant management system and carbon offsets so, earned no credits. Total earned credits under this category are (9). Considering this aspect, the building is (23.6%) efficient. The percentage contribution to a sustainable site is illustrated in figure 4.5.

Table 4.7: Assessment Criteria of Energy and Atmosphere

Energy and Atmosphere	**Credits Available**	**Credits Achieved**
Energy Efficiency Best Management Practices	Required	Available
Minimum Energy Performance	Required	Available
Building-Level Energy Metering	Required	Available
Fundamental Refrigerant Management	Required	Available
Existing Building Commissioning Analysis	2	2
Existing Building CommissioningImplementation	2	2
Ongoing Commissioning	3	0
Optimize Energy Performance	20	0
Advanced Energy Metering	2	2
Demand Response	3	3
Renewable Energy and Carbon Offsets	5	0
Enhanced Refrigerant Management	1	0
Total	38	9

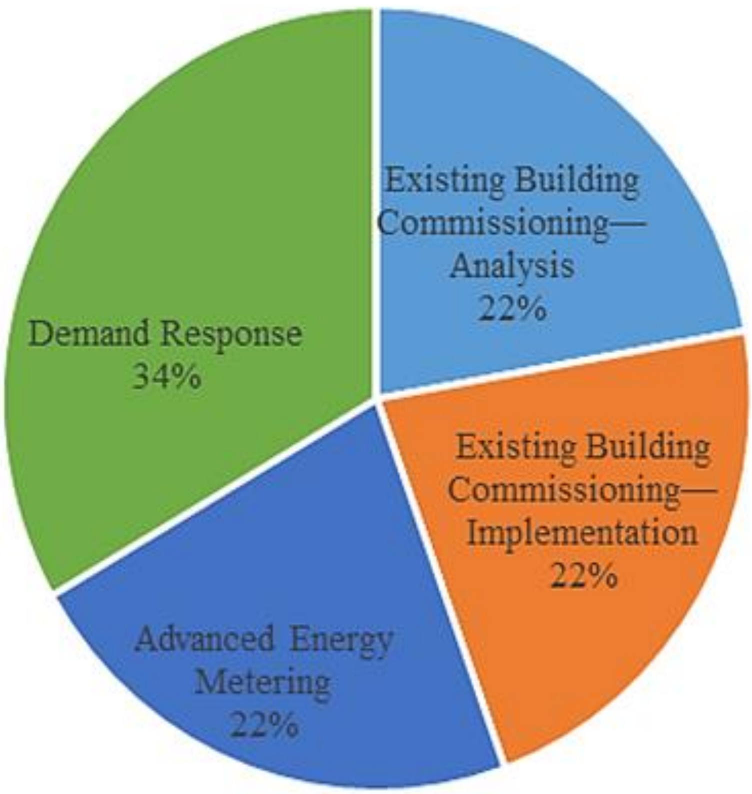

Figure 4.5: Percentage Contribution in Sustainable Sites

4.1.9 Summary of LEED Ratings

All the categories and sub-categories of LEED have been assessed. The categories earned a good ranking.

TABLE 4.8: Summary of LEED Rating Assessment

Category	**Points Available**	**Points Achieved**	**Percentage**
Regional Priority	4	1	25%
Location and Transport	15	12	80%
Material and Resources	8	3.5	43.8%
Innovation	6	0	0%
Water efficiency	12	9	75%
Indoor Environmental Quality	17	9.5	55.9%
Sustainable Sites	10	3	30%
Energy and Atmosphere	38	9	23.7%
Total	110	47	42.72%

Innovation category has not achieved any credit whereas, transport earned maximum credits of all.

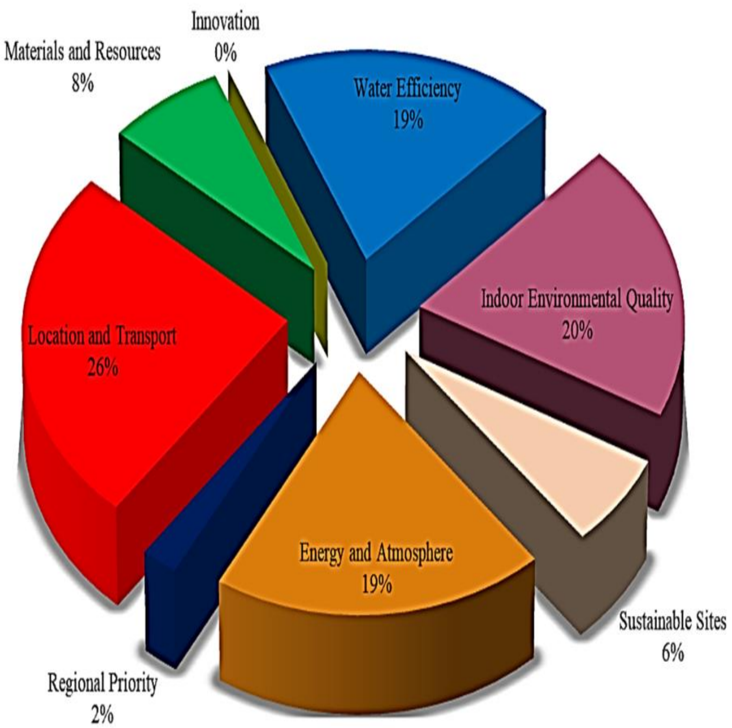

FIGURE 4.6: Percentages of Points Achieved by LEED

The total (47) credits earned out of (110) with the percentage of (42.72%). The case study achieved the GOLD certification. After assessing all the categories and sub-categories of LEED the output is shown in table 4.8. The graphical representation of the percentage of the credits by LEED assessment is shown in figure 4.6.

4.2 Sustainability Rating Assessment by BREEAM

The selected case study has been assessed by BREEAM and all the categories along with sub-categories have been assessed. All the categories are related to the sustainability rating assessment.

4.2.1 Transport

The transportation category deals with the transportation pattern of the occupants. The purpose of this category is to enhance sustainable transportation. The assessment criteria for this category are shown in table 4.9. The main purpose of this category is to minimize the usage of personal vehicles for a reduction in pollution.

Table 4.9: Transportation Assessment Criteria of BREEAM

Transport credits	**Points Available**	**Points Achieved**
Cyclist facilities	4	4
Proximity to public transport	8	8
Proximity to amenities	4	4
Pedestrian and cyclist safety	2	2
Total	18	18

For transportation category assessment following specifications are assessed: there is security arrangement for the cyclic facility in the building, public transport facility is available within 1km of the building, certain amenities are also available within 500m of the building and there is a safe footpath along the road to reach the public transport. All the facilities available so all (18) credits achieved. Considering this aspect, the building is (100%) efficient. The percentage contribution of transportation is shown in figure 4.7.

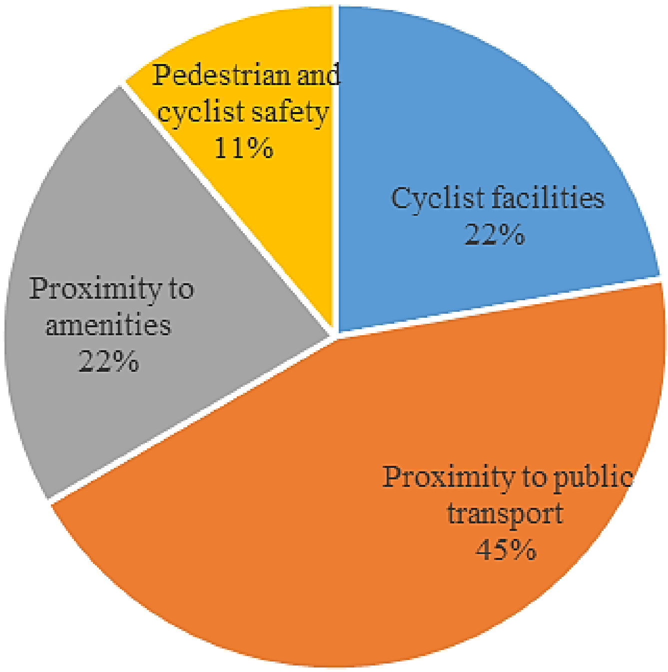

FIGURE 4.7: Percentage Contribution in Transportation

4.2.2 Waste

This category deals with the waste management and recycling of waste to produce useful materials. However, this category has no further division. For waste collection, there are bins available for specific waste like glass, paper on each floor. But no recycling process is available only (3) points allocated out of (5).

4.2.3 Water

Water efficiency deals with the smarter usage of inside and outside water. It also focuses on the utilization of greywater, recycling of water, and water-efficient devices in the building. The assessment criteria for this category are shown in the table in table 4.10.

TABLE 4.10: Water Assessment Criteria of BREEAM

Water Credits	**Credits Available**	**Credit 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

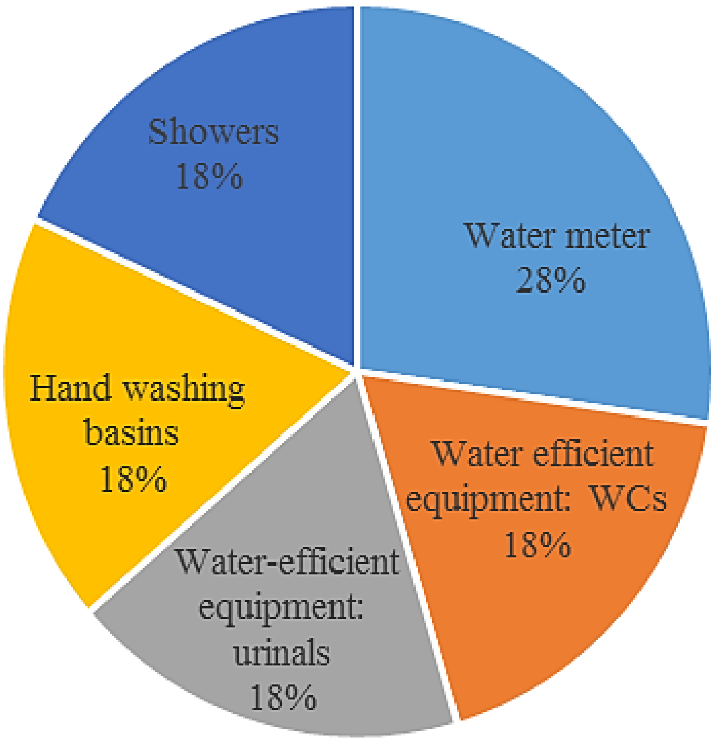

FIGURE 4.8: Percentage Contribution in Water

Water meters are installed in the selected case study so, (6) credits earned. Water closet consumes less than 4.5 liters per flush and urinal flush consumes less than

1.2 liters per flush so, (4) points earned by each sub-category. The hand wash basin has 5 liters/min flow rate and the shower has 6 liters/min so, (4) credits earned for each category. As per the plumbing drawing of the case study, there is no water leakage detection and prevention system installed in the building, no isolation valves are installed and no strategies available for reducing the water consumption so, (0) credits for each category. There is no storage and usage of rainwater in the building. The total points earned are (22) out of (40). The percentage contribution of water is shown in figure 4.8.

4.2.4 Innovation

Innovation category concerns with any other green or sustainable feature in the building other than the standards of the rating system. The building has been designed and operated on a conventional method. As per the detailed investigation of primary and secondary data, no innovation was observed in the selected case study in addition to defined the BREEAM criteria. Also, there was no BREEAM professional associated with this case study. So, out of (10) no credit earned by this category.

4.2.5 Materials

The material resources category emphasizes reducing the embodied energy and impacts by materials during all phases of construction. This category focuses on the usage of sustainable material. The assessment criteria for this category are shown in table 4.11.

For this category specifications observed were: according to the occupants, no condition survey was conducted (0) credits. No security issues are measured so, (4) credits earned. There is an alarm system available for fire alerts (4) credits earned. The alarm system is working 24 hours but no specific monitoring so, (2) credits earned. To prevent natural hazards there are plans for occupants on each floor so, (4) credits earned. During the site visit, it is observed that future changes

TABLE 4.11: Water Assessment Criteria of BREEAM

Materials Credits	**Credits Available**	**Credit Achieved**
Condition survey	4	0
Security advice	4	4
Intruder alarm system	4	4
Alarm system monitoring	4	2
Natural hazards	4	4
Future adaptation	4	4
Designing for robustness	2	0
Total	26	18

can easily be done where required (4) credits earned. There are pathways for the occupants for walking across the building. The total no. of points achieved is (18) out of (26). The percentage contribution of material is illustrating in figure 4.9.

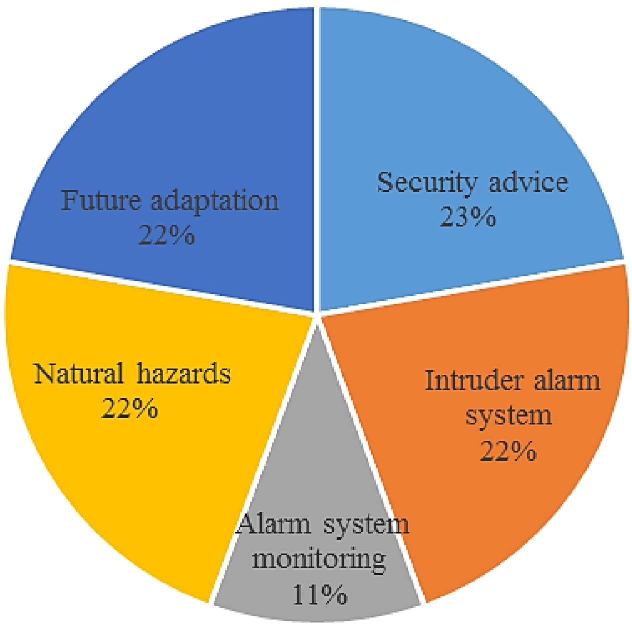

FIGURE 4.9: Percentage Contribution in Material

4.2.6 Land Use and Ecology

This category focuses on sustainable land use and long-term improvement in biodiversity in the surrounding region of the building. The assessment criteria for this category are shown in table 4.12.

TABLE 4.12: Land Use and Ecology Assessment Criteria of BREEAM

Land Use and Ecology	**Credits Available**	**Credit Achieved**
Planted area	4	2
Ecological features of the planted area	2	1
Total	6	3

There is no trend shown on vegetation in the building. Approximately 10% area is green (2) credit earned. There is a little plantation around the building (1) credit earned. Total points earned are (3) out of (6).

4.2.7 Health and Wellbeing

Health and wellbeing relate to the indoor environment quality including occupants health, thermal comfort, acoustic conditions, interior lighting, and quality views. The assessment criteria for this category are shown in table 4.13.

TABLE 4.13: Land Use and Ecology Assessment Criteria of BREEAM

Health and Wellbeing	**Credits Available**	**Credit 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

The total glazed area is not calculated as there no energy model for the building (0) credits for this sub-category. All the windows have a manual solar shading control system for glare control so (3) credits earned. To change the temperature, there is the only option available is the opening of windows (3) so credit earned. For ventilation control ventilators are installed (2) credits earned. There is no strategy available for contamination control (0) credits under this sub-category. There is a provision of water for occupants at a suitable location (2) credits earned. Benches are placed for occupants at outdoor of the building so (4) credits earned. The illuminance level is measured from lux meter and the value is 157 lux which meets the standard so (4) credits earned. For lighting control, the options are available in the sockets but not specific (3) credits earned.

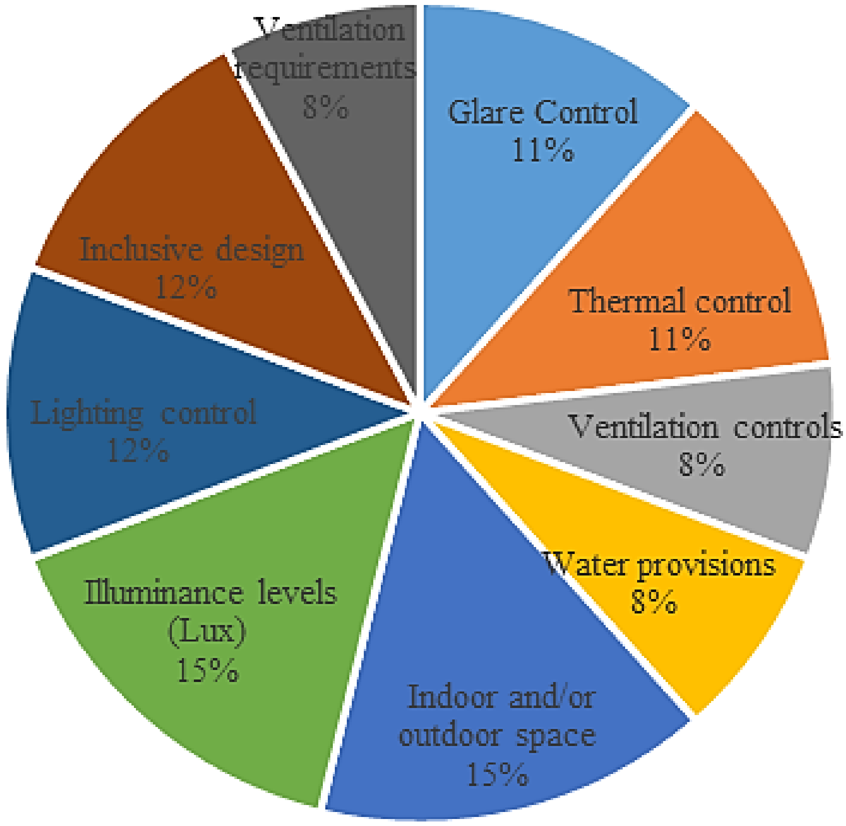

FIGURE 4.10: Percentage Contribution in Health and Wellbeing

The building has inclusive design parameters like sloping entrance, handrails, and good lighting at the entrance so (3) credits earned. The location of the building meets the ventilation requirements as it is 10m away from the external pollution source like roads so (2) credits earned. Total points earned are (26) out of (33). The percentage contribution of health and wellbeing is shown in figure 4.10.

4.2.8 Energy

This category deals with the energy consumption pattern of the building along with energy analysis, energy efficiency, and optimization of energy.

TABLE 4.14: Energy Assessment Criteria of BREEAM

Energy	**Credits available**	**Credits Achieved**
(HVAC)	(All 100 credits assessed in energy analysis)	0
Ventilation strategy		
Heat loss		
Pressure/air leakage test		
Heating		
Boiler efficiency		
Heat pump efficiency		
Fuel usage for heat generation		
Heat distribution		
Heat emitter type		
Heating equipment		
Cooling system		
The efficiency of a cooling generator		
Cooling distribution		
Air distributed cooling system		
Refrigerant cooling system		
Cooling emitter type		
Glazing		
Cooling equipment		
Specific fan power		
Leakage tests		
Ventilation equipment		
Water heating		
Water heating energy sources		
High-frequency ballast		
Internal lighting types		
Automatic lighting controls		
Occupancy sensors		
Legislation	3	0
Onsite renewables	5	4
Total	108	4

The main purpose of this category is to design buildings in such a way to use minimum energy and use renewable energy sources. The assessment criteria for this category are shown in table 4.14. The client and contractor have confirmed that the concern building has no energy modeling and analysis. However, this building has a conventional design and conventional design usually is not assessed for energy analysis. Therefore, all the credits related to energy analysis were (0) but there are solar panels available for onsite renewables with small concerns so (4) credit earned. In this category (4) credits earned out of (108).

4.2.9 Pollution

This category focuses on the reduction of noise pollution, light pollution, and air pollution that emits from the building and also give attention to the strategies on reducing pollution. The assessment criteria for this category is shown in table 4.15. There are no pollution prevention measures in the building so (0) credits for this sub-category. The building is located in a low flood risk area (4) credits earned. To reduce the pollution from surface water runoff, the building has a good drainage system and permeable surface.

Table 4.15: Pollution Assessment Criteria of BREEAM

Pollution	**Credits available**	**Credits Achieved**
Pollution prevention	4	0
Flood risk assessment	4	4
Impact mitigation	2	2
Impacts of refrigerants	4	4
Leak detection systems	4	0
NOx emissions	4	3
Total	22	13

Only small-scale refrigerants are used, so there is no significant danger from refrigerants so (4) credits earned. There is no leakage detection system in the building so (0) credits for this category. There is no such activity in the building from where NOX emits but not 100% so (3) credits earned. Total points earned are (13) out of (22). The percentage contribution of pollution is shown in figure 4.11.

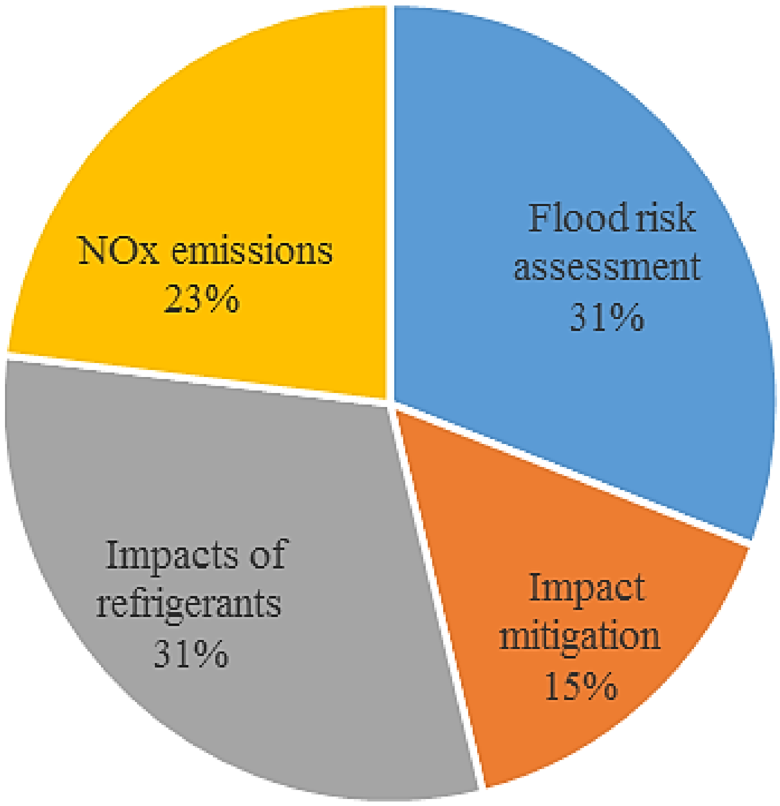

FIGURE 4.11: Percentage Contribution to Pollution

4.2.10 Summary of BREEAM Ratings

All categories and subcategories in BREEAM ratings have been assessed. The BREEAM is poor in energy and innovation category as not any credit earned under these categories. The total (107) points earned out of (267) with a percentage score of (40.0%). The GOOD certification is achieved in BREEAM. After assessing all the categories and sub-categories of BREEAM the output is shown in table 4.16. The graphical representation of the percentage of the credits by BREEAM assessment is shown in figure 4.12.

TABLE 4.16: Summary of BREEAM Rating Assessment

Category	**Credits Available**	**Credit Achieved**	**Percentage**
Transport	18	18	100%
Waste	4	3	75%
Water	40	22	55%
Innovation	10	0	0%
Materials	26	18	69.2%
Land Use and Ecology	6	3	50%
Health and Wellbeing	33	26	78.7%
Energy	108	4	3.7%
Pollution	22	13	59.1%
Total	267	107	40.0%

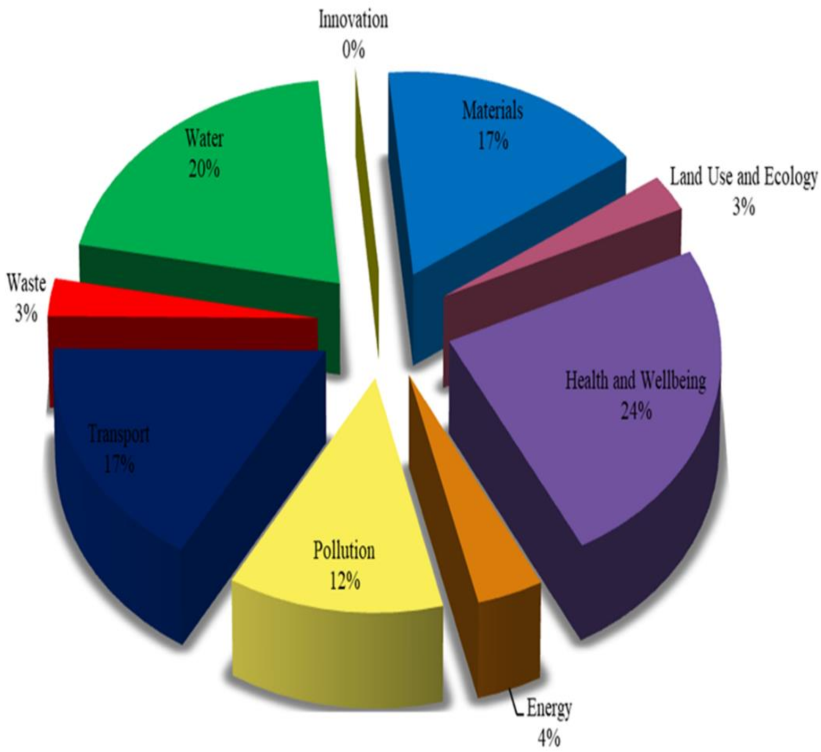

FIGURE 4.12: Percentages of Points Achieved by BREEAM

4.3 Sustainability Rating Assessment by CASBEE

The selected case study has been assessed by CASBEE and all the categories along with sub-categories have been assessed. Q environmental quality and LR environmental load are calculated and all the categories are awarded by the credits/points based upon the performance. The passing threshold for all the categories is level 3.

4.3.1 Indoor environment (Q1)

The indoor environment of the building can be assessed by the assessment of the following categories:

4.3.1.1 Sound Environment

The noise level in the building is appropriate as no noise pollution by traffic is affected by occupants. There is no such material used in the building due to which light and heavy sounds absorbed by the material. The level of achievement is 3 out of 5.

4.3.1.2 Thermal Comfort

There are no strategies available for thermal control other than the air conditions in the building. In the lobbies, good ventilation systems are installed for keeping temperature moderate. Level 2 is achieved out of 5.

4.3.1.3 Lighting and Illuminance

The orientation of the building is sustainable in which windows are facing towards the south and east direction. This location is efficient in the usage of daylight.

There are no daylight devices installed in the building. The glare is controlled by the blinds and awnings. The illuminance level is 157 lux measured from lux meter. There is no specific overall lighting control system is available in the building. Level 4 is achieved out of 5.

4.3.1.4 Air Quality

To maintain the air quality in the building ventilators are installed in suitable locations.

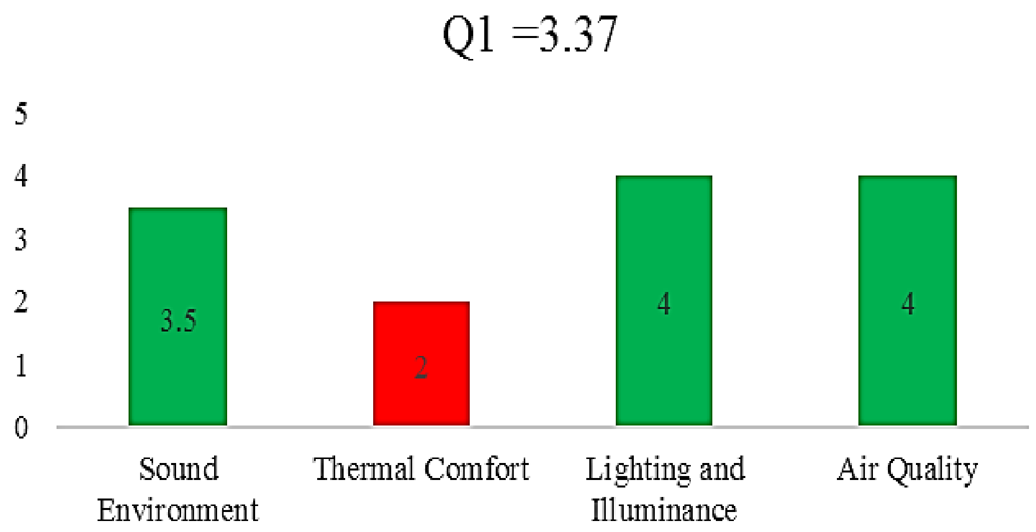

FIGURE 4.13: Score Chart of Indoor Environment Q1

The area of windows in the room is 1/8 of the total floor area of the room. The pollution sources are more than 3m away from the indoor air intake location. Smoke detectors are installed in the building to control smoking. Level 4 is achieved out of 5. The graphical representation of the level achieved by each sub-category in indoor environment Q1 is shown in figure 4.13.

4.3.2 Quality of Service Q2

The quality of service of the building can be assessed by the assessment of the following categories:

4.3.2.1 Functionality and Usability

There is a facility in the building for all occupants related to communication lines routed in all sections of the building. The height of the ceiling is 2.5m in the building which is considered as good. There are maintenance strategies available for the building. There are maintenance functions installed in the building. Level 3 is achieved out of 5.

4.3.2.2 Durability and Reliability

The design of the building illustrates that the building design based on earthquake-resistant design. but the damping system is not installed in the building to mitigate the vibrations. The external wall refurbishment period is more than 20 years. According to BOQ best material is used in the building construction. Level 4 is achieved out of 5.

4.3.2.3 Flexibility and Adaptability

There is a standard margin available for the building in the floor to floor height 2.8m and floor to load 2100N/m2. Ease is also available for future renewable of plumbing, communication cables, and electrical wires. Level 3.5 is achieved out of 5.

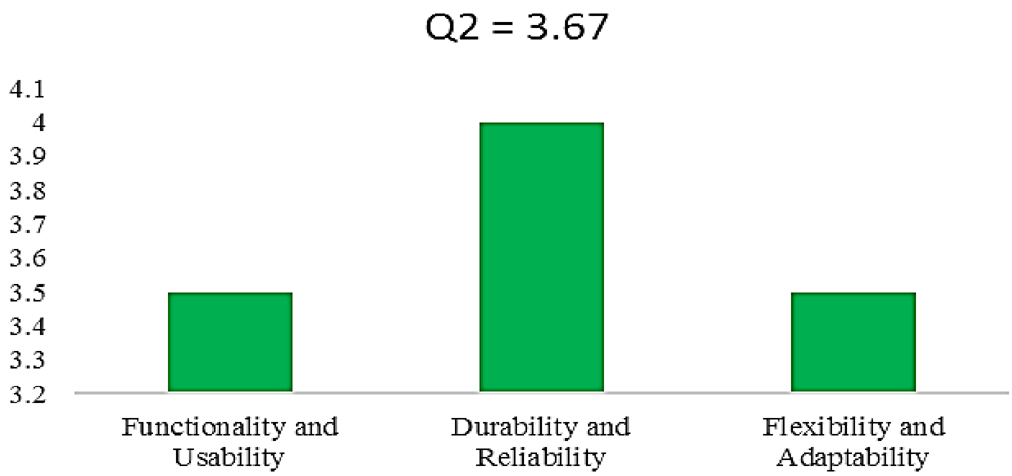

FIGURE 4.14: Score Chart of Quality of Service Q2

The graphical representation of the level achieved by each sub-category in quality of service Q2 is shown in figure 4.14.

4.3.3 Outdoor Environment Q3

The outdoor environment of the building can be assessed by the assessment of the following categories:

4.3.3.1 Preservation of Biotope

In the outdoor space of the building, less than 10% is the greenery. For crime prevention, there are security cameras that are installed outside the building. Level 4 is achieved out of 5.

4.3.3.2 Townscape and Landscape

The building is seen by the road passing. There is no equipment on the top of the roof which affects the building scenery. Level 4 is achieved out of 5.

4.3.3.3 Outdoor Amenity

Contractors confirmed the usage of locally available materials in construction.

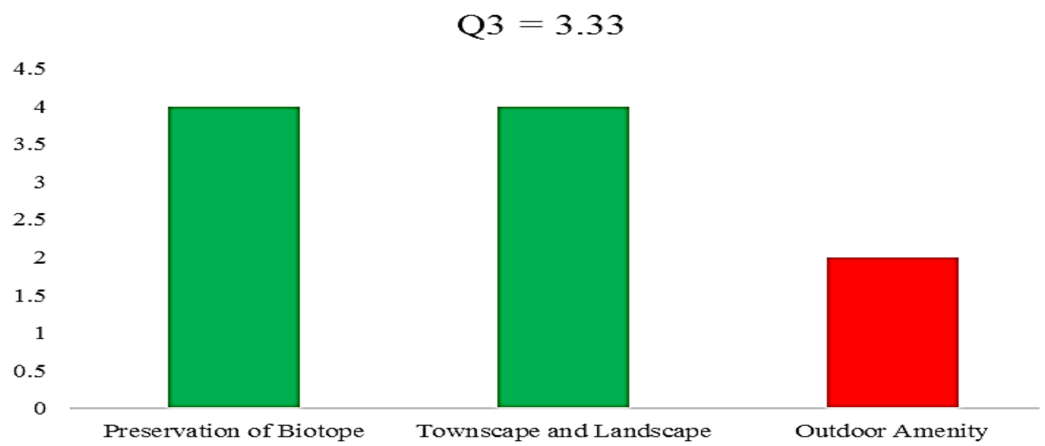

FIGURE 4.15: Score Chart of Outdoor Environment Q3

A balcony is available for the wind and light to pass through. There is no significant shelter in the outside of the building to prevent rainwater. Level 2 is achieved out of 5. The graphical representation of the level achieved by each sub-category in the outdoor environment Q3 is shown in figure 4.15.

4.3.4 Energy LR1

The outdoor environment of the building can be assessed by the assessment of the following categories:

4.3.4.1 Heat Control on the Out Surface of the Building

The BOQ has no such material which is used in the outside of the building walls for heat control. Only eaves and other shading method is used on windows. Level 3 is achieved.

4.3.4.2 Natural Energy Utilization

For the usage of natural energy solar panels are installed in the roof of the building. No other measures are taken for the usage of natural energy. Level 3 is achieved out of 5.

4.3.4.3 Building Service System Efficiency

There is no building model and energy analysis of the residential building is available to check the energy efficiency of the building. The solar system is the only energy-efficient system available. Level 1 is achieved out of 5.

4.3.4.4 Efficient Operations

Water, electricity, and gas consumption devices are installed in the building which indicates the cost consumed. The level achieved is 2 out of 5. The graphical representation of the level achieved by each sub-category in energy LR1 is shown in figure 4.16.

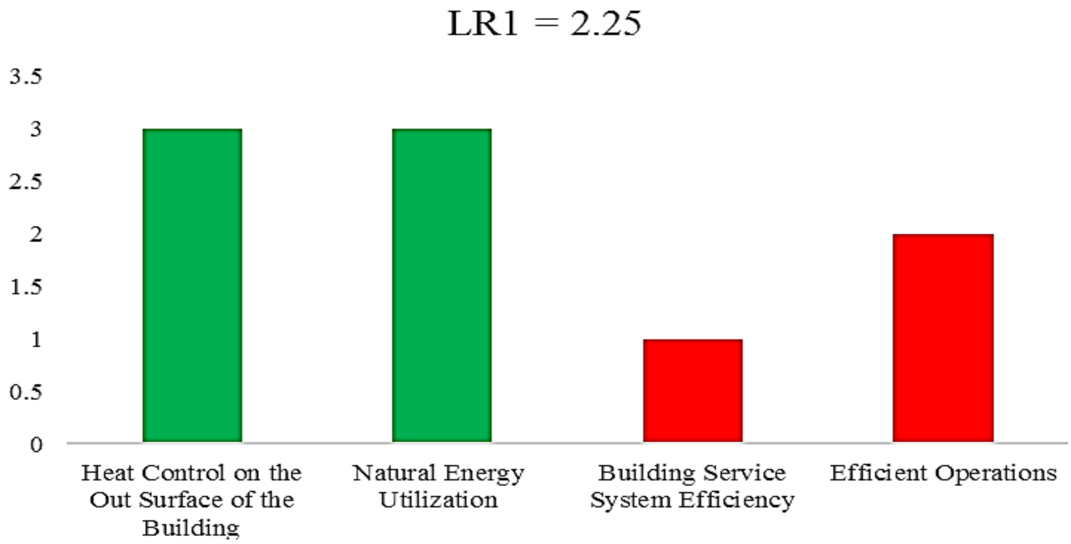

FIGURE 4.16: Score Chart of Energy LR1

4.3.5 Resources and Materials LR2

The outdoor environment of the building can be assessed by the assessment of the following categories:

4.3.5.1 Water Resources

Water-saving toilets are used in which toilets 4.5 L/use and urinals 1.2 L/use is consumed. There is no system available for the storage and use of rainwater. This building falls under less than 2000m3 so level 4 is achieved out of 5.

4.3.5.2 Reduction in Non-recycled Material Usage

High strength materials are used in the structure which contributes to the overall reduction in the material used. There is no possibility to reuse the frame of the building at the demolition stage. There is no recycled material used in the building. Level 3 is achieved out of 5.

4.3.5.3 Elimination of Pollutants

There is no pollutant material used in the wall joint, tile joint, and in wooden parts. There is no major cooling system in the building that produced hazardous gases, as small-scale refrigerants are used. Level 3 is obtained out of 5. The graphical representation of the level achieved by each sub-category in resource and material LR2 is shown in figure 4.17.

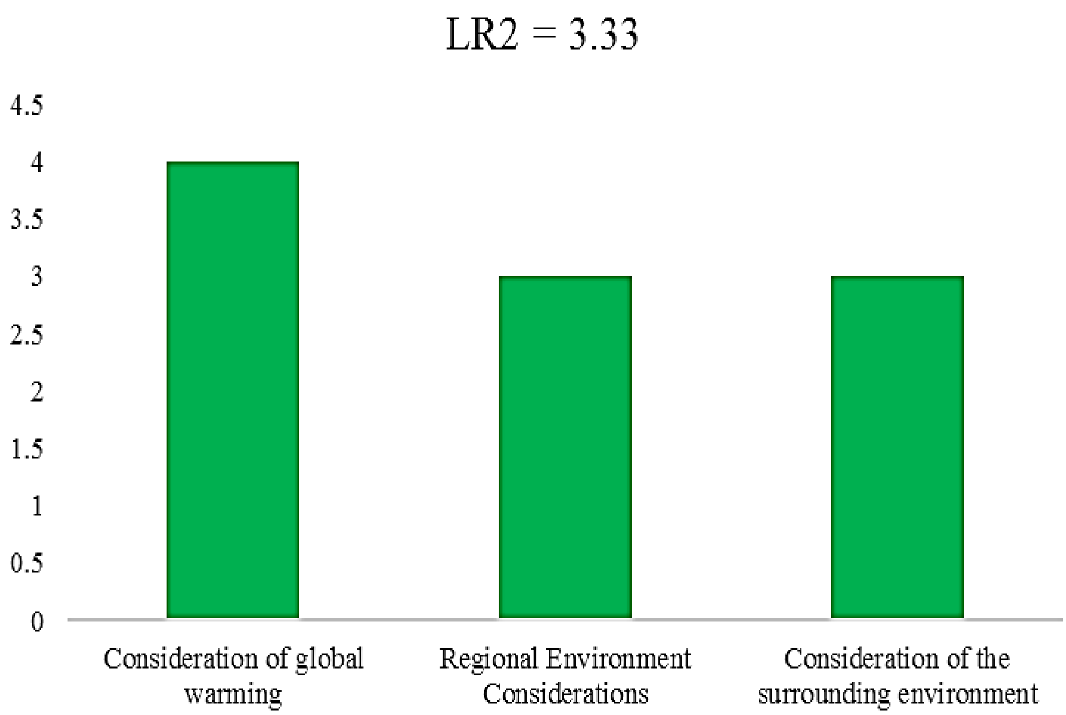

FIGURE 4.17: Score Chart of Resource and Energy LR2

4.3.6 Off-site Environment LR3

The outdoor environment of the building can be assessed by the assessment of the following categories:

4.3.6.1 Consideration of Global Warming

There are no considerations in the building construction and operation phase related to global warming. level 1 is for this category.

4.3.6.2 Regional Environment Considerations

The material used other than concrete in the exterior wall is less than 10%. No roof area is covered with evaporative material but solar panels. Level 3 is achieved out of 5.

4.3.6.3 Consideration of the Surrounding Environment

There are no guidelines at the administrative level for sewerage load suppression and rainwater load reduction control. Parking facility and security is available for the building occupants. Level 3 is achieved out of 5. The graphical representation of the level achieved by each sub-category in the off-site environment LR3 is shown in figure 4.18.

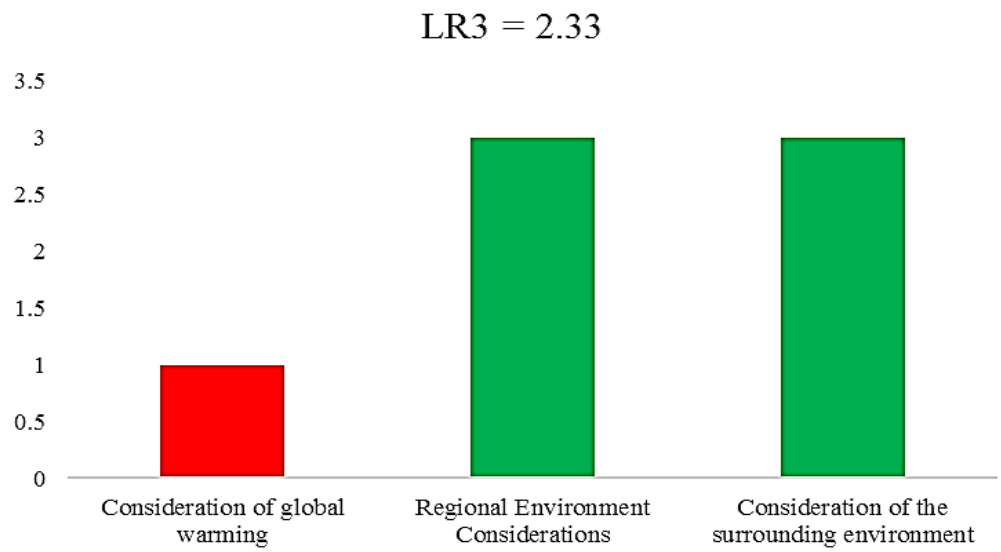

FIGURE 4.18: Score Chart of Off-Site Environment LR3

4.3.7 Radar Chart of Major Categories in CASBEE

All categories of Environment Quality (Q): Q1, Q2, Q3 has been assessed and the level of ranking has been marked. Similarly, the ranking Environmental Load Reduction LR and its categories: LR1, LR2 LR3 has also been assessed. The radar chart is shown in figure 4.29.

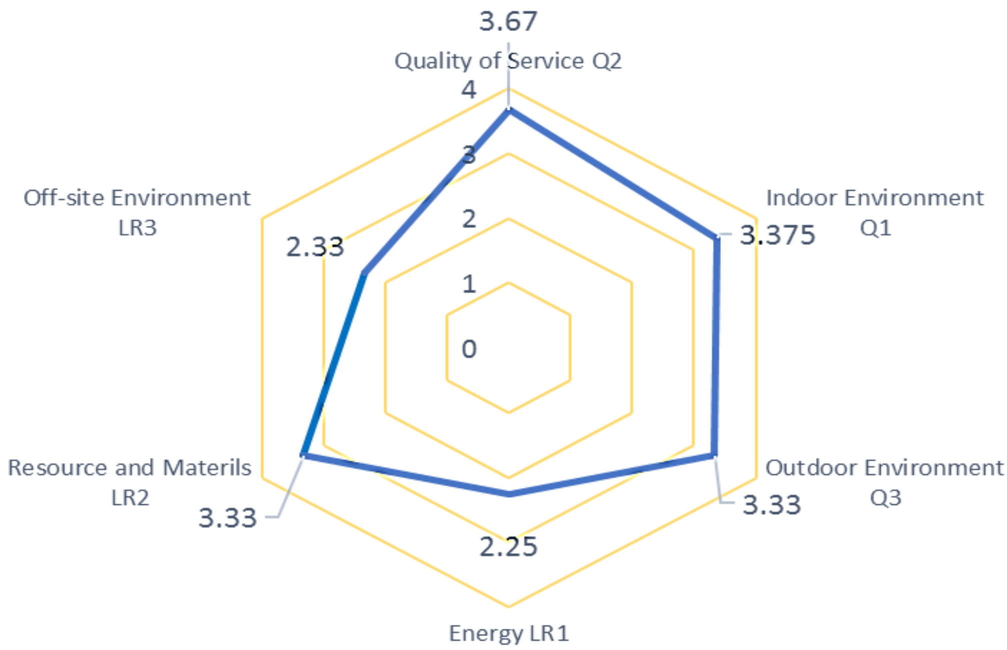

FIGURE 4.19: Radar Chart of CASBEE Categories

4.3.8 BEE Calculation and CASBEE Certification

Build environment efficiency is calculated by the assessment values of Q and LR. The final values of Q and LR are calculated from the SQ and SLR. To convert the Q scale from (1 to 5) to (0 to 100) the Q =25(SQ-1). Similarly, the L is converted from (0 to 5) to (1to 100) by the L= 25(5-SLR). The BEE value is calculated from the formula [91] page 9.

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

Q= Environmental Quality of Building

L= Environmental Load of Building

BEE $= \frac{(25*(SQ-1))}{(25*(5-SLR)}$

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

BEE $= \frac{61.25}{59.25}$

BEE =1.03

4.3.9 Summary of CASBEE Ratings

All the categories lie in the environmental quality and the load of the building has been assessed and ranked. The BEE value has been calculated from L and Q. The value obtained after calculated is 1.03. The B+ grade is achieved with three stars and Good certification.

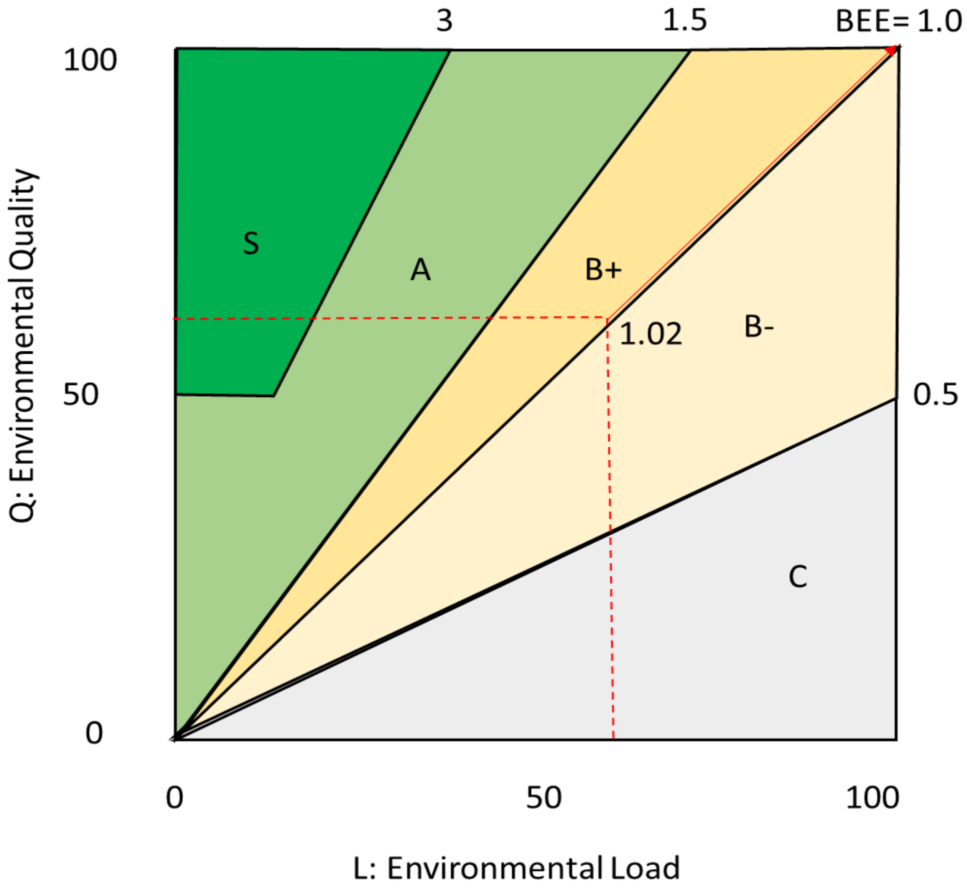

FIGURE 4.20: Assessment Rating by CASBEE

4.4 Sustainability Rating Assessment by Green Star

Green Star system has been applied to the selected case study and all the categories along with sub-categories have been assessed. The following are the categories assessed in this rating system.

4.4.1 Land Use and Ecology

This category focuses on sustainable land use and long-term improvement in biodiversity in the surrounding region of the building. The assessment criteria for this category is shown in table 4.17.

TABLE 4.17: Land Use and Ecology Assessment Criteria of Green Star

Land Use and Ecology	**Credits available**	**Credits Achieved**
Heat Island Effect	1	0
Sustainable Sites	2	2
Ecology Value	3	1
Total	6	3

In ecology and land use, these categories are assessed. According to the contractor, there are no ecological communities at the project site before the start of the project. Only vegetation was present at the site location. The site contains no hazardous material before construction and there is no developed land at the project site before construction so (1) credit earned. There are no strategies available on the project site that contributes to the heat island effect so (0) credits for this sub-category. (3) credits achieved out of (6) under this category. The percentage contribution of land use and ecology is shown in figure 4.21.

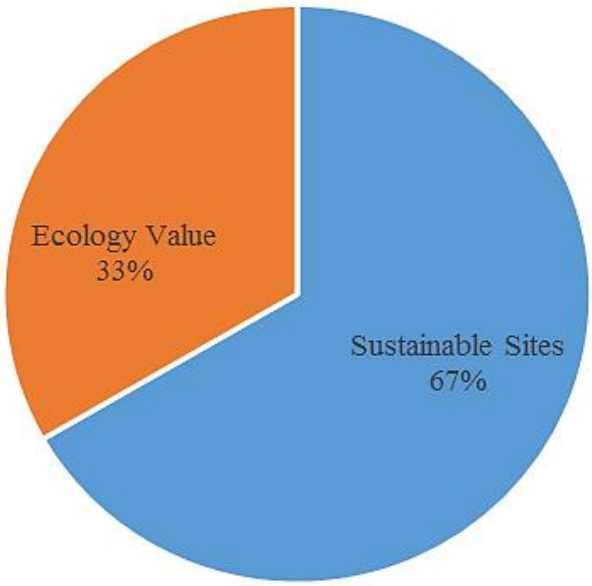

FIGURE 4.21: Percentage Contribution in Land Use and Ecology

4.4.2 Indoor Environment Quality

Indoor environment quality relates to the health and wellbeing of the occupants including thermal comfort, acoustic conditions, interior lighting, and quality views. The assessment criteria for this category are shown in table 4.18.

TABLE 4.18: Indoor Environment Quality Assessment Criteria of Green Star

Indoor Environment Quality	Credits available	Credits Achieved
Indoor Air Quality	4	2
Acoustic Comfort	3	1
Lighting Comfort	3	2
Visual Comfort	3	3
Indoor Pollutants	2	1
Thermal Comfort	2	1
Total	17	10

The ventilation system is installed in the building to remove indoor pollutants no other arrangement is available so (2) credits earned. There is also a specific open space is available for natural ventilation of the indoor area. There is no such activity in the building which affect the occupants' internal sound comfort. No sound absorption material is used in the building so (1) credits earned. All the lights in the living spaces are flickered-free. There is no living space with wall-washing fitting.

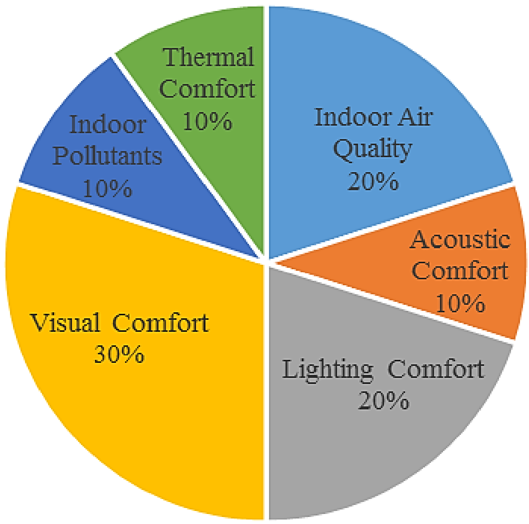

FIGURE 4.22: Percentage Contribution to Indoor Environmental Quality

Occupants have control over adjusting the lights but up to a certain level so (2) credits earned. Blinds are available at windows to control the glare effect. Daylight is checked through the lux meter and the value is 157 lux which meets the standards (3) credits earned. Paints and wood used in the building are of good quality and considers as creating no indoor pollution by these things other parameters are not considering so (1) credit earned. There is no thermal comfort strategy at the building level other than air conditioning (1) credit earned. (11) points earned under this category. Considering this category, the building is (64.7%) efficient. The percentage contribution of indoor environment quality is shown in figure 4.22.

4.4.3 Materials

The material resources category emphasizes reducing the embodied energy and impacts by materials during all phases of construction. This category focuses on the usage of sustainable material.

TABLE 4.19: Materials Assessment Criteria of Green Star

Materials	**Credits available**	**Credits Achieved**
Life Cycle Impacts	7	0
Responsible Building Materials	3	3
Sustainable Products	3	2
Construction and Demolition Waste	1	1
Total	14	6

The assessment criteria for this category are shown in table 4.19. According to the client and contractor, no LCA was performed on the concern case study so (0) credits for this sub-category. All the steel, timber, and other materials used in the building construction mentioned in the BOQ had been purchased from a responsible source so (3) credits earned. No recycled material is used in the building so (2) credits earned. All the waste generated during construction was diverted to landfills so (1) credit earned. Total (6) credits earned out of (14) under this category. In this aspect, the building is 42.8% efficient. The percentage contribution of materials is shown in figure 4.23.

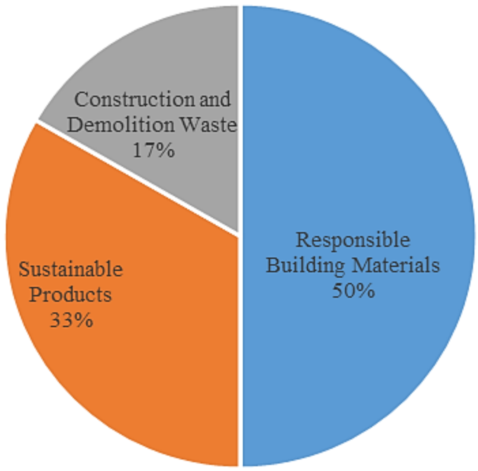

FIGURE 4.23: Percentage Contribution in Materials

4.4.4 Transportation Facilities

The transportation category deals with the transportation pattern of the occupants. The purpose of this category is to enhance sustainable transportation. The assessment criteria for this category are shown in table 4.20.

TABLE 4.20: Transportation Facilities Assessment Criteria of Green Star

Transportation Facilities	**Credits available**	**Credits Achieved**
Parking facility	2	2
Public Transport	2	1
Prohibition Signage	2	2
Amenities	4	2
Total	10	7

There are transportation facilities available for the occupants. Public transport is available within 400m of the building but not transit system so (1) credit earned. The parking facility is available for the occupants having cars, bicycles, and cycles so (2) credits earned. Do not park signage are available for occupants using pollution creating/ bad condition vehicles so (2) credits earned. There are also 7 amenities available within the 500m of the building so (2) credits earned. Total (7) points are achieved out of (10). In this aspect, the building is 70% efficient. The percentage contribution of transportation facilities is shown in figure 4.24.

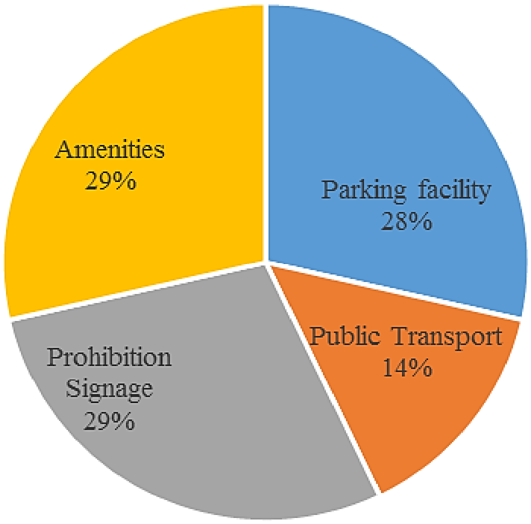

FIGURE 4.24: Percentage Contribution to Transportation Facilities

4.4.5 Innovation

Innovation category concerns with any other green or sustainable feature in the building other than the standards of the rating system. As per the detailed investigation of primary and secondary data, no innovation was observed in the selected case study in addition to defined Green Star criteria. Also, there was no Green Star professional associated with this case study. So, out of (10) no credit earned by this category.

4.4.6 Energy

This category deals with the energy consumption pattern of the building along with energy analysis, energy efficiency, and optimization of energy. The main purpose of this category is to design buildings in such a way to use minimum energy and use renewable energy sources. The assessment criteria for this category are shown in table 4.21.

There is no automatic occupant detection system is installed in the building to reduce energy consumption. All living units are separately switched. The power

Table 4.21: Energy Assessment Criteria of Green Star

Energy Credits	Credits available	Credits Achieved
Greenhouse Gas Emissions	20	6
Peak Electricity Demand Reduction	2	2
Total	22	8

to hot water systems is provided by natural gas rather than electricity no other strategies available so (6) credits earned. Solar panels are installed at the roof in peak energy demand (2) credits earned. Total (8) points are achieved under this category. Considering this aspect, the building is 36.3% efficient.

4.4.7 Emissions

This category focuses on the reduction of noise pollution, light pollution, and air pollution that emits from the building and also give attention to the strategies on reducing pollution. The assessment criteria for this category are shown in table 4.22.

Table 4.22: Emissions Assessment Criteria of Green Star

Emissions	Credits available	Credits Achieved
Stormwater	2	0
Light Pollution	1	0
Microbial Control	1	0
Refrigerant Impacts	1	1
Total	5	1

There is no system available by which rainwater can be stored and reused so (0) credits for this category. There is no awning installed outside the building to stop the light pollution to the neighborhood at night so (0) credits for this category. There is no system available for microbial control (0) credits for this category. There is no refrigerant system installed at the building level (1) credit earned. Total (1) point achieved under this category. Considering this aspect, the building is 20% efficient.

4.4.8 Management Aspects

This category focuses on sustainable construction practices to be adopted during all construction phases. The assessment criteria for this category are shown in table 4.23.

TABLE 4.23: Management Assessment Criteria of Green Star

Management	Credits available	Credits Achieved
Green Star Accredited Professional	1	0
Commissioning and Tuning	4	0
Adaptation and Resilience	2	0
Building Information	1	0
Commitment to Performance	2	2
Metering and Monitoring	1	1
Responsible Construction Practices	2	2
Operational Waste	1	1
Total	14	6

FIGURE 4.25: Percentage Contribution in Management Aspects

There was no green star accredited professional involved in the project so (0) credits for this category. The maintenance policy is available for the project. Water and energy consumption meters are installed in the building (1) credit earned. No commissioning and adaption and resilience mechanism (0) points for this category. As informed by the contractor, the construction practices were very responsible at the site and all team was highly qualified, training was also conducted from time to time during construction (2) credits earned and all waste was diverting to the landfill (1) credit earned. 6 points achieved under this category. Considering this aspect, the building is 42.8% efficient. The percentage of contribution management is illustrating in figure 4.25.

4.4.9 Water

This category deals with the smarter usage of inside and outside water. It also focuses on the utilization of greywater, recycling of water, and water-efficient devices in the building. The assessment criteria for this category are shown in table 4.24.

TABLE 4.24: Water Assessment Criteria of Green Star

Potable Water	**Credits available**	**Credits Achieved**
Rainwater Usage	2	0
Water usage in the HVAC system for heat rejection	2	2
Water metering	1	1
Water leakage detector system	3	0
Other sources of water for plantation	2	0
Total	12	3

According to plumbing drawings, there were no water tank for rainwater storage (0) credits for this sub-category. There was no HVAC system at the building level to use water for heat rejection (2) credits earned. There is no water leakage detector system installed in the building (0) credits for this sub-category. Water meters are installed to measure water consumption so (1) credit earned. There is no alternative water system is available to give water to plants so (0) credits for this sub-category. Total (3) points earned under this category. Considering this aspect, the building is 25% efficient. The percentage of contribution water is shown in figure 4.26.

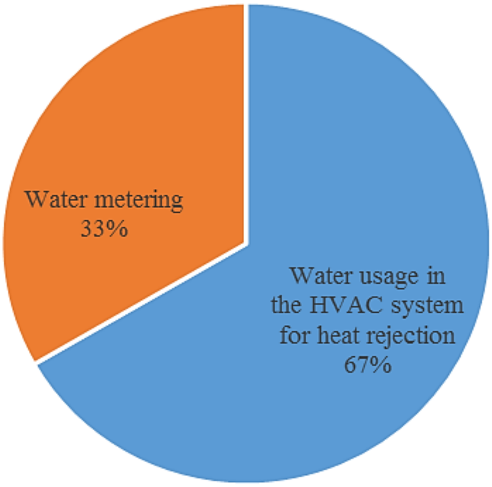

FIGURE 4.26: Percentage Contribution in Water

4.4.10 Summary of Green Star Ratings

All nine categories of the Green Star Rating system have been assessed. The case study earned good points in some categories like Transportation facilities and indoor environmental quality. Innovation category not achieved even a single point. Total no. of credits earned are 44 out of 110 with certification level of GOOD PERFORMANCE. The summary of the Green Star rating is shown in table 4.25.

TABLE 4.25: Summary of Green Star Ratings

Category	**Points Available**	**Points Achieved**	**Percentage**
Land use and ecology	6	3	50%
Indoor environment quality	17	10	58.8%
Materials	14	6	42.8%
Transportation Facilities	10	7	70%
Innovation	10	0	0%
Energy	22	8	36.3%
Emissions	5	1	20%
Management Aspects	14	6	42.8%
Water	12	3	25%
Total	110	44	40.0%

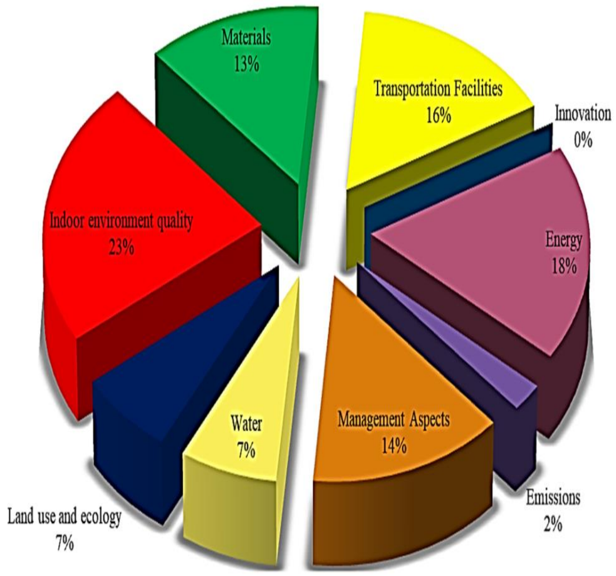

FIGURE 4.27: Percentages of Points Achieved by Green Star

The graphical representation of the percentage of the credits by Green Star assessment is shown in figure 4.27.

4.5 Sustainability Rating Assessment by BEAM Plus

BEAM Plus system has been applied to the selected case study and all the categories along with sub-categories have been assessed. The following are the categories assessed in this rating system.

4.5.1 Water Use

This category deals with the smarter usage of inside and outside water. It also focuses on the utilization of greywater, recycling of water, and water-efficient devices in the building. The assessment criteria for this category are shown in table 4.26. There was no plan available at the management level to conserve the water.

No sensor water fixtures are installed to save water. Several tests were performed on the water to check the quality of water (3) credits earned.

Table 4.26: Water Assessment Criteria of BEAM Plus

Water Use	Credits available	Credits Achieved
Water Efficient Devices	4	0
Water use for irrigation	1	0
Cooling Tower	1	0
Water-saving performance	4	3
Quality water supply	3	3
Water metering	1	1
Water audit	2	0
Enhancement	3	2
Twin-tank System	2	0
Water Efficient Flushing System	2	2
Total	24	11

For irrigation purposes, the conventional method is under usage because there is no greywater or rainwater storage system in the building (0) credit for this category. No water recycling system is installed. No water audit was performed at the building so (0) credits for this category. The training was conducted at the start of a project to enhance the water-saving sense but not regularly (2) credit earned.

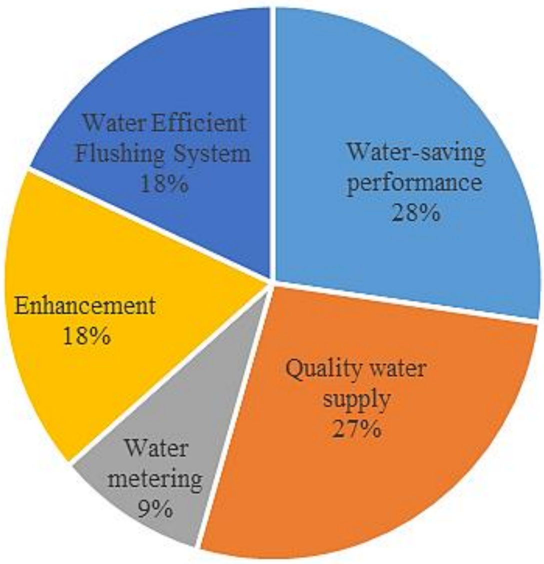

Figure 4.28: Percentage Contribution in Water

According to the contractor, a good quality plumbing system was installed in the building for good performance. Water meters are installed to measure the consumption of water regularly which helps occupants to conserve water (1) credit earned. There was no twin-tank system in the building so (0) credits for this category. Dual flush systems are installed in all the toilets of the building so (2) credits earned. (11) credits earned out of (24). Considering this aspect, the building is (45.8%) efficient. The percentage of contribution water is shown in figure 4.28.

4.5.2 Site Conditions

Sustainable sites refer to ensure that the natural environment has importance throughout the building life. The outdoor environment of the building should also give importance to the indoor environment. The assessment criteria for this category are shown in table 4.27.

Table 4.27: Site Conditions Assessment Criteria of BEAM Plus

Site Aspects	**Credits available**	**Credits Achieved**
Green Building Attributes	7	5
Noise Pollution	2	2
Light Pollution	2	2
Heat Island Reduction	1	0
Corporate Social Responsibility Facilities/ Services	4	4
Amenities for Operation and Maintenance	3	2
Barrier-Free Access	3	3
Total	22	18

Only certain green building attributes are available in the building so (5) credits earned. The parking facility is available for the building occupants with proper security. Public transport is within 500m from the building. Seven different basic facilities are within 500m of the building. Some benches are available outside the building for sitting (4) credits earned. There is no vertical greenery or shades to cater to the heat island effect (0) credits earned. Exhaust fans installed for ventilation are not the cause of noise pollution for occupants (2) credits earned. External lights are installed outside the building but turned off till mid-night (2) credits earned. There is no green roof of the selected case study. Barrier-free access is available for special persons (3) credits earned. Total (18) points achieved under this category out of (22). By considering this aspect, the building is (81.8%) efficient. The percentage of contribution site conditions is illustrating from figure 4.29.

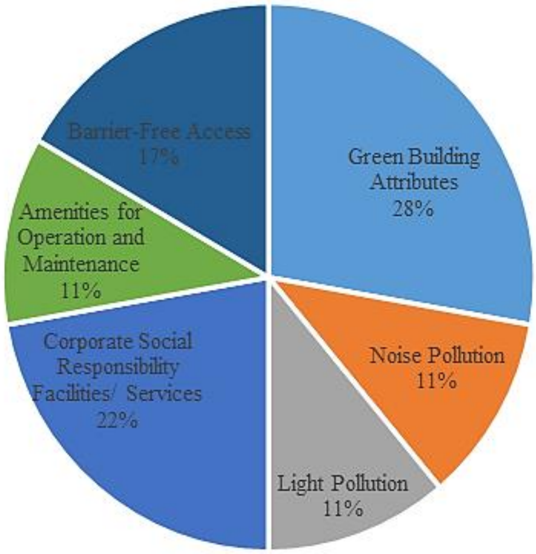

FIGURE 4.29: Percentage Contribution in Site Conditions

4.5.3 Material and Waste

The material resources category emphasizes reducing the embodied energy and impacts by materials during all phases of construction. This category focuses on the usage of sustainable material and recycling of waste. The assessment criteria for this category are shown in table 4.28.

No green or sustainable material was purchased to use in the building, according to BOQ, all the conventional material was used (0) credits for this category. There is no waste recycling system available in the building. No cooling system was installed at the building level which affects ozone depletion (3) credits earned. There is no food waste recycling system in the building (0) credits for this category.

Table 4.28: Material and Waste Assessment Criteria of BEAM Plus

Materials and Waste Aspects	**Credits available**	**Credits Achieved**
Materials Purchasing Practices	5	0
Ozone Depleting Substances	3	3
Waste Management Plan	1	0
Recycling facilities for different waste streams	4	0
Food Waste Management	1	0
Action to Waste Reduction	3	1
Total	17	4

All the waste generated during construction was diverted to the landfill, with no action concern towards waste reduction so only (1) credit earned. Total (4) credits earned out of (17) under this category. The percentage of materials and waste aspects is shown in figure 4.30.

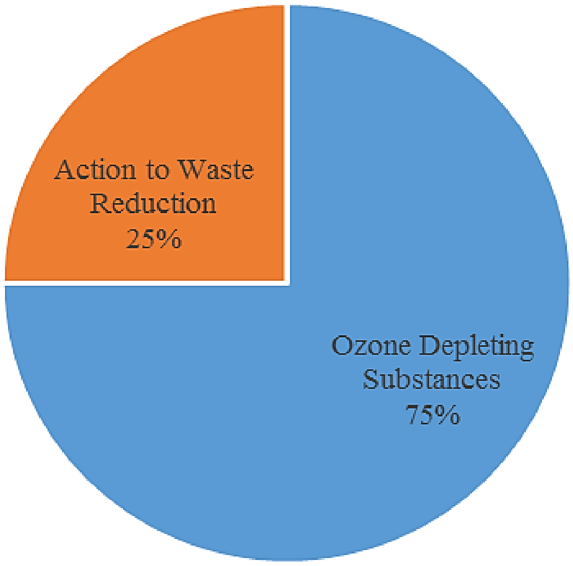

Figure 4.30: Percentage Contribution in Materials and Waste Aspects

4.5.4 Indoor Environment Quality

Indoor environment quality relates to the health and wellbeing of the occupants including thermal comfort, acoustic conditions, interior lighting, and quality views. The assessment criteria for this category are shown in table 4.29.

Table 4.29: Indoor Environment Quality Assessment Criteria of BEAM Plus

Indoor environment quality	Credits available	Credits Achieved
Building User Satisfaction	3	2
Ventilation in Common Areas	2	2
Localized Ventilation	2	2
Thermal Comfort	2	1
Biological Contamination	2	0
Waste Disposal Facilities	1	1
Control of Environmental Tobacco Smoke	2	2
Interior Lighting in Normally Occupied Area	3	3
IAQ Monitoring	7	1
Room Acoustics	1	1
Noise Isolation	1	1
Total	26	16

Occupant's satisfaction features like good lighting and cleanliness are under consideration (2) credits earned. There are outdoor spaces available in the building for natural ventilation. The ventilation facility is available in all living spaces and all the necessary locations of the building (2) credit earned for each aspect. There are no strategies available for biological contamination in the HVAC system (0) credits for this category.

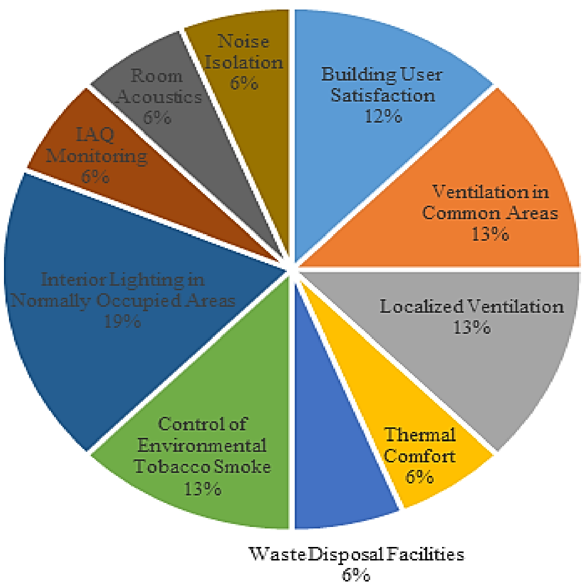

Figure 4.31: Percentage Contribution in Indoor Environment Quality

For the prohibition of smoking in the building, area signs are posted at all necessary locations of the building (2) credits earned. There is no light related and acoustic issues in the living spaces (1) credit for each category. No sound absorbed materials used in the building to avoid noise. (16) credits achieved under this category out of (26). By considering this aspect, the building is (61.50%) efficient. The percentage of materials and waste aspects are illustrating in figure 4.31.

4.5.5 Management Aspects

This category focuses on sustainable construction practices to be adopted during all construction phases. The assessment criteria for this category are shown in table 4.30.

TABLE 4.30: Management Aspects Assessment Criteria of BEAM Plus

Management	**Credits available**	**Credits Achieved**
EHS and Energy Management System	3	0
Environmental, Social and Governance (ESG) Disclosure	1	1
BEAM Professional	2	0
Staff Training and Resources	2	2
Building and Site Operation and Maintenance	2	2
Building Services Operation and Maintenance	7	3.5
IAQ Management for Renovation	2	0
Green Cleaning	2	0
Integrated Pest Management	1	0.5
User Guidance	1	1
Total	23	10

There are no management system for energy and environmental health and safety so (0) credits for this category. No BEAM Plus professional involved in the project (0) credits for this category. There was no green material purchasing policy and sustainability policy available in the project (0) credits for this category. Staff training was made at the start and when necessary (2) credits earned. There is a policy available for the maintenance and service operations of the building within the contracted time, but this was followed by approximately half of the time (3.5) credits earned. There is a strategy available for pest control (0) credits earned. There was given the user guide before the operation phase of the building (1) credit earned. Total (9) credits earned out of (23) under this category. The percentage of management aspects are illustrating in figure 4.32.

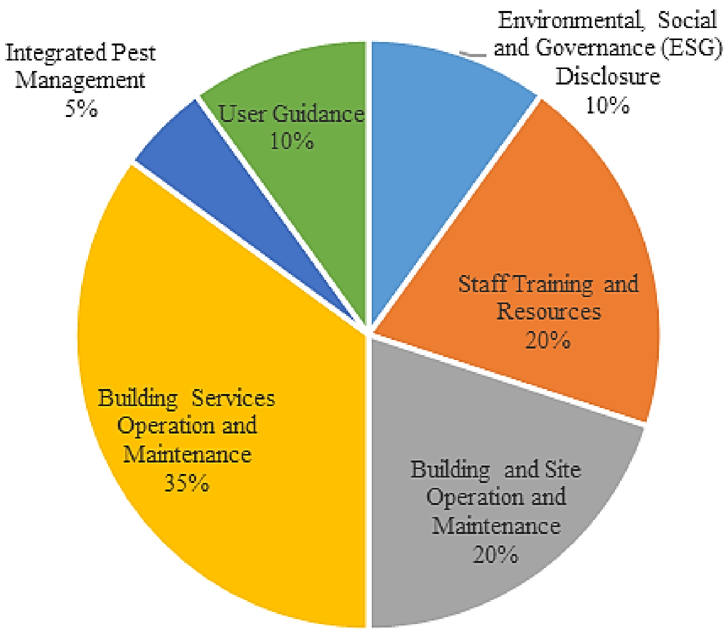

FIGURE 4.32: Percentage Contribution in Management Aspects

4.5.6 Energy Use

This category deals with the energy consumption pattern of the building along with energy analysis, energy efficiency, and optimization of energy. The main purpose of this category is to design buildings in such a way to use minimum energy and use renewable energy sources. The assessment criteria for this category are shown in table 4.31.

There is no energy management policy in the building (0) credits for this category. Energy consumption meters are installed but no sub-meter is installed for the cooling system. There is no air-conditioning system is at the building level, so

Table 4.31: Energy Assessment Criteria of BEAM Plus

Energy	**Credits available**	**Credits Achieved**
Energy management	4	0
Energy analysis	11	0
Commissioning	12	0
Energy improvement	12	6
Total	39	6

no commissioning is required. No modeling and energy analysis was performed on the building (0) credits earned. Only solar panels are installed at the roof for peak energy demand. (6) credits earned. By considering this aspect the building is (15.3%) efficient.

4.5.7 Innovation

Innovation category concerns with any other green or sustainable feature in the building other than the standards of the rating system. As per the detailed investigation of primary and secondary data, no innovation was observed in the selected case study other than the BEAM Plus criteria. Also, there was no BEAM Plus professional associated with this case study. So, out of 10 no credit earned by this category.

4.5.8 Summary of BEAM Plus Ratings

All seven categories including innovation of the BEAM Plus rating system have been assessed. Case study lack in earned points in energy and innovation categories but some categories like site selection and indoor environmental quality achieved good points. Total no. of credits earned is (65) out of (161) with (40.4%) and certification level of BRONZE. After assessing all the categories and sub-categories of BEAM Plus the output is shown in table 4.32. The graphical representation of the percentage of the credits by BEAM Plus assessment is shown in figure 4.33.

Table 4.32: Summary of BEAM Plus Rating Assessment

Category	Credits Available	Credit Achieved	Percentage
Water Use	24	11	45.8%
Site Conditions	22	18	81.8%
Material and Waste	17	4	23.5%
Indoor Environment Quality	26	16	61.5%
Management Aspects	23	10	43.5%
Energy Use	39	6	15.4%
Innovation	10	0	0%
Total	161	65	40.4%

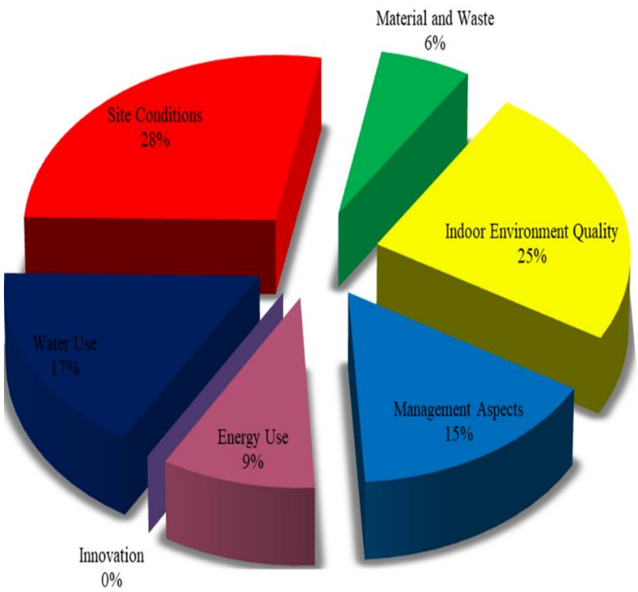

Figure 4.33: Percentages of Points Achieved by BEAM Plus

4.6 Comparative Analysis

The case study has been assessed by implementing all the selected rating tools. Each rating tool assessed the building by its categories and credits available. The certification has been awarded to a case study by all rating systems. The comparison of all the selected rating tools is shown in table 4.33. Energy is the most important category in all the rating systems, but the case study lacks in energy category because most of the energy subcategories are assessed by energy modeling and analysis the case study has not any energy model and analysis.

Table 4.33: Comparison of Attributes of Rating Tools

Categories/Rating Tools	**LEED**	**BREEAM**	**CASBEE**	**Green Star**	**BEAM Plus**
Site Aspects	3	3	6.6	3	18
Transport	12	18	-	7	-
Energy	9	0	4.5	8	6
Water	9	22	-	3	11
Material Resources	3.5	18	6.6	6	4
Indoor Environmental Quality	9.5	26	6.7	10	16
Management	-	-	-	6	10
Pollution	-	13	-	1	-
Waste	-	3	-	-	-
Innovation	0	0	-	0	0
Off-site Environment	-	-	4.6	-	-
Quality of Service	-	-	7.3	-	-
Regional Priority	1	-	-	-	-
Total Credits Available	110	267	BEE=3.00	110	161
Total Credits Achieved	47	107	BEE= 1.02	44	65
Percentage of Achievement	42.72%	40.00%	34.0%	40.00%	40.4%
Stars Rating	-	3 stars	3 Stars	3 stars	-
Final Certification	Gold Certified	Good Certified	Good (B+)	Good Performance	Bronze Certified

Only LEED and Green Star award maximum (9) and (8) points respectively to the energy category as compared to other systems. BREEAM not awarded even a single point to energy because of all the energy subcategories based on energy analysis. The water category earned maximum points (11) by BEAM Plus as compared to other tools. LEED and BREEAM award (9) and (22) credits to water respectively. Green Star awards minimum (3) points. CASBEE has not any water-related category and subcategory to assess in the building. Transportation facilities are mainly focused on LEED and BREEAM with (12) and (18) points respectively. All the subcategories related to transportation are fulfilled by a case study in LEED and BREEAM systems. Green star awarded an average score of (7). CASBEE has some transportation-related aspects in the off-site environment. But BEAM Plus has no attention towards sustainable transportation. Site aspects are the category that is assessed by all rating systems. BEAM Plus awards maximum (18) points under this category. Similarly, CASBEE also awards good points and assessed this category under the onsite environment category. LEED, Green Star, and BREEAM have strict criteria to award points to this sustainable aspect. The material resources category is also assessed by all rating tools as the site conditions category. CASBEE and Green Star awarded almost equal points (6.6) and (6) respectively. Minimum points awarded by LEED (3.5) as compared to other rating systems. CASBEE has not the water-related category separately but assessed some water aspects under this category. Management is the category that is only assessed by the BEAM Plus and Green Star. LEED and BREEAM have not assessed the management aspects of the case study. CASBEE assessed some management aspects under the quality of service category. Out of all the systems BEAM Plus strongly assessed the management and awarded (10) points. LEED is the only rating system that focused on the regional priority and assessed in the case study but awarded only (1) credit. On the other hand, CASBEE also assessed regional priority aspects under the off-site environment. BEAM Plus, CASBEE, and BREEAM have not this category. The case study has not such features in the building that leads to earning credits under the innovation category. There is no innovation in the building other than the rating systems categories. No additional credit earned by case study under this category. Pollution is mainly focused on BREEAM as the case study earned (13) credits by BREEAM. Green Star also has a pollution category with the name of emissions, but only (1) credit awarded. LEED and BEAM Plus has no pollution category to assess in the case study. CASBEE assessed this category under materials as a pollutant emission and earned level (3). Indoor environmental quality is assessed by all selected tools. Although BREEAM has many criteria to assess this category but award maximum points as compared to other tools (26) credits. Green Star, LEED, and BEAM Plus awarded (10), (9.5), and (16) respectively. CASBEE has strict criteria to assess indoor environment quality of building and achieved (3.37) level. Waste is only focused on BREEAM and earned (3) credits. Other rating tools have no separate category of the waste but assessed this category under material and resources.

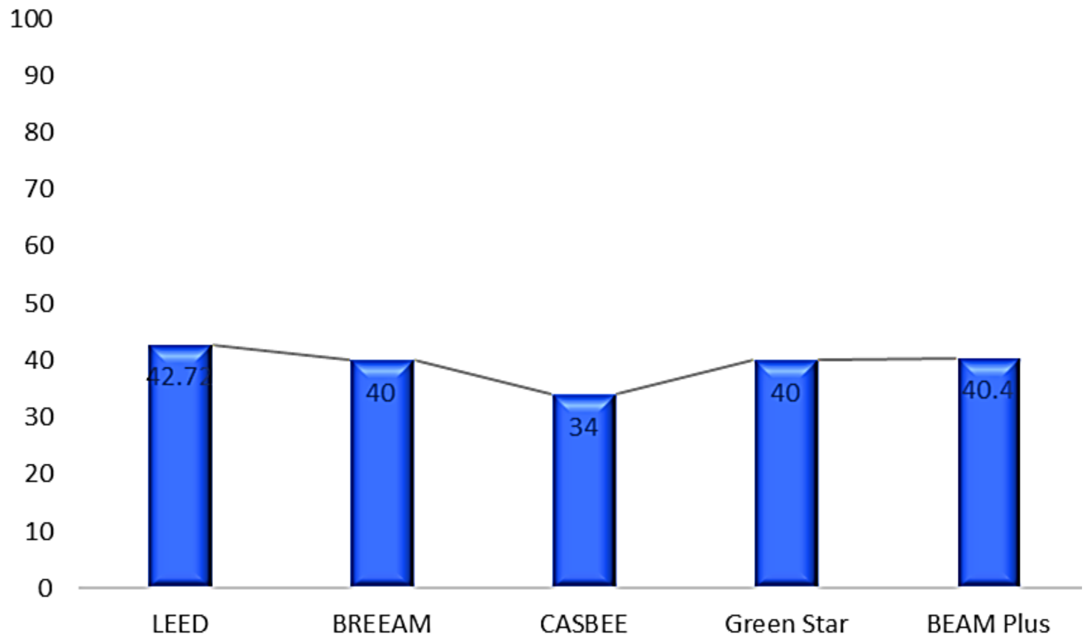

FIGURE 4.34: Comparison of the Final Score of Rating Tools

The case study earned (47) credits out of (110) by LEED. These credits lie between the threshold of GOLD CERTIFICATION. So, the case study is GOLD CERTIFIED by LEED. BREEAM awarded cumulative (107) credits out of (267) with 40% and achieved GOOD RATING. This is the three-star certification. The minimum performance of the case study is shown by CASBEE. The BEE obtained after the calculation is (1.02). This value marginally meets the B+ grade with three-stars ranking. The certification level is GOOD. Green Star awarded total (44) credits out of (110) with GOOD PERFORMANCE certifications. Stars' rating is similar to other tools as three-stars. The case study earned minimum credits in BEAM Plus (65) out of (165) with 40.4% and achieved BRONZE CERTIFICATION. (40) is the minimum limit to get certified by BEAM Plus. Results show that the overall rating tools certification is consistent. Case study achieved maximum credits by LEED.

4.7 Top Rating Categories in GBRTs

A sustainability rating assessment has been performed by the applicability of five selected rating tools. After a detailed comparative analysis, the top five rating categories in GBRTs have been observed. Table 4.34 illustrates the categories having maximum credits.

TABLE 4.34: Comparison of Top Rating Categories of GBRTs

Rating Tools	**Rating 1**	**Rating 2**	**Rating 3**	**Rating 4**	**Rating 5**	**Total Percentage**
LEED	Location and Transport (10.9%)	Energy (8.2%)	Indoor Environment Quality (8.6%)	Water Efficiency (8.1%)	Materials (3.2%)	39.0%
BREEAM	Health and Wellbeing (9.73%)	Transport (6.7%)	Pollution (4.86%)	Water Efficiency (8.23%)	Materials (6.74%)	36.26%
CASBEE	Quality of Service (6.6%)	Indoor Environment Quality (6.1%)	Materials (6%)	Site Aspects (6%)	Off-site Environment (4.2%)	28.80%
Green	Star Indoor Environment Quality (9.0%)	Energy (7.2%)	Transport (6.7%)	Materials (5.5%)	Management (5.5%)	33.90%
BEAM	Plus Water (6.83%)	Indoor Environment Quality (9.93%)	Site Conditions (11.18%)	Materials (2.48%)	Management (6.21%)	36.60%

Table 4.34 illustrates that, In the LEED rating system, location and transport contribute 10.9%, energy 8.2%, indoor environment quality 8.6%, water 8.1%, and materials 3.2% to the final score. The top five categories contribute 39.0% to the overall score in LEED. In the BREEAM rating system, health and wellbeing contribute 9.73%, transport 6.7%, pollution 4.86%, water efficiency 8.23%, materials 6.74% to the final score. The top five categories contribute 36.26% in overall score in BREEAM. In the CASBEE rating system, quality of service contributes 6.6%, indoor environment quality 6.1%, materials 6%, site aspects 6%, and the off-site environment contributes 4.2% to the final score. The top five rating categories

contribute 28.80% to the overall score. In the Green Star rating system, indoor environment quality contributes 9%, energy 7.2%, transport 6.7%, materials 5.5% and management contribute 5.5% to the final score. The top five categories contribute 33.3% to the overall rating score. In the BEAM Plus rating system, water contributes 6.83%, indoor environment quality 9.93%, site aspects 11.18%, materials 2.48%, and management contribute 6.21% to final rating score. The top five rating categories contribute 36.60% to the overall rating. It is observed in each rating system assessment, indoor environment quality contribution is significant. The materials category is also in the top five rating categories of selected GBRTs.

4.8 Triple Bottom Line of Sustainability and GBRTs

The triple bottom line of sustainability refers to environmental, social, and economic aspects. After the assessment of the case study by rating tools, a comparison between the triple bottom line of sustainability and rating tool is conducted. Table 4.35 illustrates that the case study earned 42.72% credits by LEED rating assessment in which 22.3% credits are of environmental aspect, 20.43% credits are of the social aspect and the economic aspect does not contribute in any credits. In the BREEAM assessment, the case study earned a total of 40% credits in which 23.6% credits are of the environmental aspect, 16.43% credits are of the social aspect and the economic aspect has no credit. In CASBEE, a total of 34% credits earned in which 20.3% credits are of environmental aspect, 6.1% credits are of the social aspect, economic aspect has no credit and 6.6% credits are of other aspects. In Green Star, total credits are 40%, in which 19.1% credits are of environmental aspect, 15.45% credits are of the social aspect, no credit earned by economic aspect, and 5.45% credits are of other aspects. In BEAM Plus total of 40.4% credits earned, in which 24.2% credits are of environmental aspect, 9.93% credits are of the social aspect, economic aspect contributes no credit, and 6.21% credits are of other aspects.

Table 4.35: Comparison of Triple Bottom Line and GBRTs

Pillars of Sustainability	LEED	Percentage Achieved	BREEAM	Percentage Achieved	CASBEE	Percentage Achieved	Green Star	Percentage Achieved	BEAM Plus	Percentage Achieved
Environmental	i. Sustainable Sites	(22.3%)	i. Land Use and Ecology	(23.6%)	i. Energy	(20.3%)	i. Land Use and Ecology	(19.1%)	i. Water Use	(24.2%)
	ii. Energy and Atmosphere		ii. Energy		ii. Resource and Materials		ii. Energy		ii. Material and Waste Aspects	
	iii. Water Efficiency		iii. Water		iii. Outdoor Environment		iii. Water		iii. Site Conditions	
	iv. Material Resources		iv. Materials		iv. Offsite Environment		iv. Materials		iv. Energy Use	
			v. Pollution				v. Emissions			
			vi. waste							

Social	i. Indoor Environment Quality	(20.43%)	i. Transport	(16.43%)	i. Indoor Environment	(6.1%)	i. Indoor Environment Quality	(15.45%)	i. Indoor Environment Quality	(9.93%)
	ii. Location and Transport iii. Regional Priority		ii. Health and Well-being				ii. Transportation Facilities			
Economic	-	(0%)	-	(0%)	-		-	(0%)	-	(0%)
Others	Innovation	(0%)	Innovation	(0%)	Quality of Service	(6.6%)	i. Management ii. Innovation	(5.45%)	i. Management Aspects ii. Innovation	(6.21%)
Total		42.74%		40.03%		34%		40%		40.4%

The case study is socially sustainable by all rating systems more or less, which means that transportation facility to occupants, internal atmospheric conditions of the building, occupants health and well-being and regional priority is good. Similarly, environmental sphere of sustainability also earns maximum credits by all systems which are approximately consistent. Some features are before the start of the construction like sustainable sites and material usage of the building but maximum categories are assessed during operational phase of the construction like water efficiency, energy usage patterns of the building and pollution. The main categories of the selected rating tools have not any economic related issue. The current research found that the conventional residential building in the selected region is environmentally sustainable maximum by BREEAM rating tool but the overall rating is not highest from all the tools. The social sustainability is maximum by LEED and similarly the overall score of the LEED is also maximum by all other systems. CASBEE rating system is adopted to judge the other categories rather than environmental, social and economic pillar.

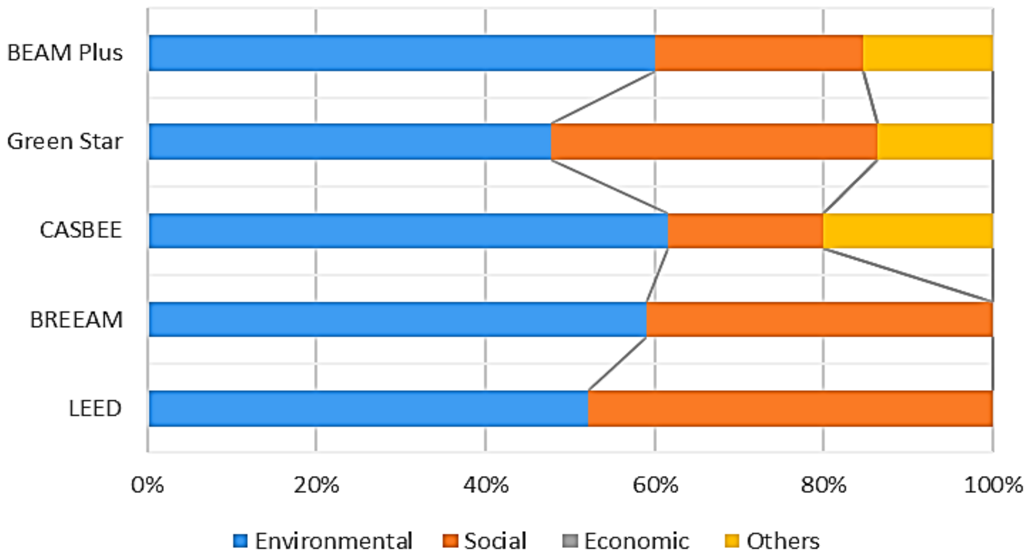

Figure 4.35: Graphical Representation of the Triple Bottom Line of Sustainability and GBRTs

The Green Star rating system has minimum environmental score of out of all rating system but social aspect is considerable. BEAM Plus rating system has second highest score of environmental aspect but other categories are incorporated. By assessment of all categories and analysis of triple bottom line of sustainability the LEED rating tool is reasonable for this region to assess the sustainability of the residential building. Figure 4.35 illustrates that the environmental aspect of sustainability is achieved by five rating systems. The maximum environmental sustainability is achieved by BREEAM. The social aspect is also achieved by the five rating systems. Maximum social sustainability is achieved LEED. The economic aspect is not achievable by any rating system. Sustainability by some other aspects is achieved in CASBEE, Green Star, and BEAM Plus.

4.9 Summary

In this chapter, the assessment of the case study is conducted by the application of five rating tools. main and sub-categories of rating tools have been assessed. The graphical representation of credits earned in each sub-category is presented. In addition to that, a detailed comparative analysis of the results of five rating tools is conducted. A comparison is conducted to observe the top five contributor categories in each rating tool. Finally, a detailed comparison between the rating tool and the triple bottom line of sustainability is conducted. It is concluded that the case study has features to obtain the certification by five rating tools.

Chapter 5

Conclusions and Recommendations

This chapter concludes the research work. Recommendations have also been suggested for future work. The chapter is divided into two sections. The first section concludes the research work. The second part deals with future recommendations. Rating tools have been applied to the selected case study. Sustainability assessments by the application of green building rating tools have been performed. Individual assessment and comparative analysis have been accomplished to represent the sustainability level of the building.

5.1 Conclusions

The conclusions from the research are as follows:

- The case study achieved a sustainability rating of 42.72% by LEED, 40.01% by BREEAM, 40.00% by Green Star, and 40.40% by BEAM Plus. So, it is more sustainable by LEED than other systems.

- The CASBEE has a different assessment pattern. It assessed the building on the level scale rather than credit or points weighting. BEE value of 1.02

obtained from these rating tools when converted to a points system becomes equal to 34%.

- Assessment performance level obtained by case study GOLD by LEED, GOOD by BREEAM, GOOD with B+ grade by CASBEE, GOOD by Green Star and BRONZE by BEAM Plus.
- All rating tools assessed almost similar performance levels, but the assessment rating level of LEED i.e. GOLD is distinct by all other rating tools. From individual and comparative analysis, LEED is the most suitable rating tool for assessment in this region.
- From all assessed categories in the selected rating tools, energy and innovation lack to obtained credits but LEED and Green Star assessment case study earned some credits in energy. The energy category in other systems requires modeling and energy analysis to assess credits, but the case study has not this data for analysis. There are no innovation presents in the building other than rating system requirements.
- The concern building achieved maximum sustainability in environmental aspect followed by social. However, economic aspect was lacking.
- Based upon comprehensive comparative analysis, indoor environment quality achieved maximum contribution by all rating tool.
- This study can be helpful for the construction sector to mitigate the features that lack to obtain a good sustainability rating assessment.

5.2 Future Recommendations

Based upon the assessment results, individual and comparative analysis and conclusions of the research work it is recommended that:

- The construction industry should follow rating tools during the design, construction, and demolition phase to explore sustainability.

- Energy modeling and analysis should be mandatory for all buildings to obtain good credit and overall best rating assessments.

- The economic pillar of sustainability should be inculcated in the rating tools to enhance their applicability.

- The performance level of a traditional building can be improved by incorporating basic innovative ideas and energy consumption to perform analysis. Energy modeling and analysis should be mandatory for all buildings to obtain good credit and overall best rating assessments.

- A further study can be executed for a non-traditional building case study and observe the points of major concern for the improvement of traditional design criteria.

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Annexure A

A survey was conducted to know about the transportation pattern of the occupants of the building for the assessment of the transportation category of LEED. The following questions are evaluated from the obtained data.

Demographic Data

1. Building occupants using personal vehicles

a) 0-1 b) 2-3 c) 4-5 d) more than 5

2. Building occupants using walking or biking

a) 0-1 b) 2-3 c) 4-5 d) more than 5

3. Building occupants using ride shares

a) 0-1 b) 2-3 c) 4-5 d) more than 5

4. Building occupants using public transport

a) 0-1 b) 2-3 c) 4-5 d) more than 5