BUILDING PERFORMANCE SCORE MODEL FOR ASSESSING THE SUSTAINABLE PERFORMANCE IN LIFE CYCLE OF BUILDING

Thesis

Submitted in partial fulfillment of the requirement for the degree of

Doctor of Philosophy

by

THANU H P

(155075CV15P02)

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALURU - 575 025

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DECLARATION

I hereby *declare* that the Research Thesis entitled "**Building Performance Score Model for Assessing the Sustainable Performance in Life Cycle of Building**", which is being submitted to the **National Institute of Technology Karnataka, Surathkal** in partial fulfilment of the requirements for the award of the Degree of **Doctor of Philosophy** in the **Department Of Civil Engineering** is a *bonafide report of the research work carried out by me*. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

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CERTIFICATE

This is to *certify* that the Research Thesis entitled **BUILDING PERFORMANCE SCORE MODEL FOR ASSESSING THE SUSTAINABLE PERFORMANCE IN LIFE CYCLE OF BUILDING** submitted by **Mr. THANU H P** (Register Number: 155075CV15P02), as the record of the research work carried out by him, is accepted as the Research Thesis submission in partial fulfilment of the requirements for the award of degree of Doctor of Philosophy.

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ABSTRACT

The construction industry is one of the major sectors contributing to the economic development of our country. This industry also acts as a significant source of pollution towards environment and the impact of these are very severe. To overcome this impact, the concept of sustainability in the construction sector has emerged. This concept helps maintain proper balance in environment and ensure that the natural habitats are not disturbed. In the coming years, vital importance is given to the concept of sustainability and various rating tools to measure the performance of green buildings.

However, with critical reviews on the current tools, they are criticized as being ineffective and inefficient in addressing the building performance issues, as most of them only focus on assessing building performance on environmental criteria and the assessment does not take into consideration economic and social analysis. Sustainability is like a three-legged stool, with each leg representing areas of environment, economy and society. Any leg missing from the 'sustainability stool' will cause instability because the three components are intricately linked together. In addition, most current tools have not considered all the building phases in their assessment. As economic, social and environmental impacts associated with project development will vary at different stages throughout its life cycle, sustainable performance should be assessed and incorporated into the building process.

In the Indian context, the existing building assessment tools emphasise more on environmental impact rather than economical and social impacts. To address this issue, the Building Performance Score (BPS) model is developed pertaining to building sustainability based on triple bottom line priorities, consisting of environmental, economical, and social concepts. Therefore the aim of this study is to identify the assessment indicators based on triple bottom line and develop a conceptual model to assess the buildings for their sustainability performance. This model includes 44 indicators that play a significant role in the sustainability assessment of construction buildings. Different phases in the life cycle of building are identified and corresponding

indicators in each stage that influence environmental, economic and social aspects are also identified. Among the total indicators, there are 19 environmental indicators, 12 economic indicators, and 13 social indicators. A questionnaire survey and semi-structured interviews were conducted to collect the data. Both quantitative and qualitative methods are used in this study. The questionnaire survey was conducted online, and 123 people responded positively. The survey was conducted to deduce the building stage divisions and the pertaining indicators. The outcome of this study specifies that various indicators such as the topographical and climate change, health and safety of the construction workers, project management consultancy, risk management, security measures, and solid waste management forms a chief source of a sustainable building and these indicators are not being assessed in the existing assessment tools. Moreover, these indicators are also required to be assessed and included in the evaluation process while assessing the performance of the building. Also, consideration of environmental, economic and social factors is equally important in construction industry.

Formulation of BPS model is based on the identified indicators obtained from questionnaire survey and literature review. Analytic Hierarchy Process (AHP) is used to identify the importance of assessment indicators. Further, various assessment methods such as Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Value Score (VS) are also used for evaluation of indicators. In the present study, three different certified green buildings were considered and performance assessment of the building was carried out using the BPS model. The BPS for the three case studies is 7.24, 4.47 and 7.92 respectively. Their corresponding LEED certified scores are 54 (Platinum), 41 (Gold) and 57 (Platinum). Moreover, the Building Performance Score (BPS) indicates the sustainable performance of the building. The assessment is carried out at every stage which gives a proper understanding to the stakeholders regarding the impact of every stage. This will also help in undertaking required changes in the design in order to be more sustainable before the actual construction of the building begins. The characteristic of BPS model of considering all the three aspects for assessment, total cost incurred and impact on local society is an added advantage for the stakeholders to assess the project.

From the study, it is evident that considering economic and social aspects along with environmental aspects for assessment of buildings is necessary which is missing in the existing assessment tools. With the incorporation of various indicators for assessment, a better performance assessment result for the building can be obtained. Hence this BPS model proves to be an enhanced approach in building performance assessment throughout the complete life cycle of the building.

The benefits and outcome of BPS model are also discussed in this research. This research supports a sustainable building assessment tools which is different from other approaches and maintains that it is essential to apply sustainable assessment at various phases of building development cycle. Other assessment tools provide environmental performance of the project, whereas BPS provides sustainable performance that considers the impacts of sustainability aspects at every phase of the building development cycle. The BPS model offers a detailed vision regarding the building performance assessment process and will surely aid the achievement of construction practices that are sustainable for the Indian construction industry. Hence, this model can be used for assessing the sustainable performance of any building in India and other developing countries by incorporating respective regional criterion.

Keywords: Building Assessment Tools, Triple Bottom Line of Sustainability, Building Process, Building Performance Score, Assessment Indicators, Analytic Hierarchy Process.

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NOMENCLATURE

AHP	Analytical Hierarchy Process
BA	Building Assessment
BAT	Building Assessment Tools
BEE	Bureau of Energy Efficiency
BERAC	Biological and Environmental Research Advisory Committee
BPS	Building Performance Score
BREEAM	Building Research Establishment Environmental Assessment Method
CF	Carbon Footprint
CII	Confederation of Indian Industry
CPCB	Central Pollution Control Board
EAT	Environmental Assessment Tools
EF	Ecological Footprint
EIA	Environmental Impact Assessment
EPI	Energy Performance Index
FCA	Full Cost Accounting
GB	Green Building
GFA	Gross Floor Area
GHG	Greenhouse Gas
GRIHA	Green Rating for Integrated Habitat Assessment
HK - BEAM	Hong Kong - Building Environmental Assessment Method
HVAC	Heating, Ventilation and Air Conditioning
IGBC	Indian Green Building Council
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCCA	Life Cycle Cost Assessment
LCEA	Life Cycle Energy Analysis

LEED	Leadership in Energy and Environmental Design
MNRE	Ministry of New and Renewable Energy
SA	Sustainable Assessment
SAT	Sustainable Assessment Tool
SD	Sustainable Development
SDA	Sustainable Development Ability
SIA	Social Impact Assessment
TBL	Triple Bottom Line
TCA	Total Cost Accounting
TERI	The Energy and Resources Institute
USGBC	U.S. Green Building Council
VS	Value Score
WF	Water Footprint

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In the present situation, the construction sector is considered one of the primary sources of the negative impact on the environment. This is due to the growing global population, urbanization, and increase in resource consumption. In India, the building sector alone accounts for about 15% to 18% of total carbon dioxide emissions and about 30% to 50% of SO_2 emissions (Vyas and Jha, 2016). It is anticipated that the energy requirement will rise at an average rate of 3.2% annually in rapidly developing countries like India. By 2020, it may even exceed the energy requirements in developed countries (Bhatt and Macwan, 2016). Development is needed to meet the basic facilities required using the available resources without affecting future generations' lives. Due to this, the concept of green building and sustainability in construction has gained immense importance worldwide. The building assessment tools (The Leadership in Energy and Environmental Design - LEED-India and Green Rating for Integrated Habitat Assessment - GRIHA) help to evaluate the building performance, but these tools consider only the environmental aspect and do not holistically consider the complete sustainable assessment of buildings. Sustainability can be achieved when environmental, economic, and social aspects are considered in measuring the performance of buildings. Also, these assessment tools lack the role of life cycle stages of building and their impact. In order to make these assessment tools more relatable to the concept of sustainability, it is necessary to develop an assessment model by considering the three major pillars of the building life cycle.

1.2 BACKGROUND TO THE WORK

Construction industry is one of the major sources of environmental pollution (Vyas and Jha, 2018). The environmental problems caused by construction range from energy and resource consumption to waste production throughout the building life cycle (Ding and Shen, 2010; Vyas and Jha, 2016). But the fact that the development of construction industry leads to the country's economic and social development cannot be unobserved. Hence, it is required to develop a sustainable construction methodology and while doing so measures must be considered that the natural habitats are not disturbed. With the greater prominence shown towards the concept of green and sustainable construction developments, various tools have been developed in recent years in order to measure the performance of such sustainable and green buildings. In the Indian context, the assessment tools developed to measure the performance of the green building are found to be scanty in addressing various economic and social impacts.

Green building is considered to be one of the practices toward sustainable construction which ensures minimal impact on the environment throughout the life cycle of the building (Vyas and Jha, 2018). These practices help to reduce the energy consumption in a building (Mokhtar Azizi et al., 2014). Therefore, sustainable development is considered to be a vital factor in the sustainable performance of buildings (Al-Qawasmi, 2019). In order to analyze this, various Sustainable Assessment Tools (SATs) are in practice. These tools are also recognized by the government both at local and national levels. In utilizing the existing assessment tools that are developed in other countries, it is required to ascertain with minor modifications depending on the context, nature, and the environment. Also, it is to be understood that, existing assessment tools in India cannot satisfactorily fulfill the assessment in a given context, as they cannot match with differing Indian conditions such as local economic, climatic and different cultural conditions, and hence an assessment tool that satisfactorily suits Indian conditions is necessary. Amongst the several tools for building assessment, LEED INDIA and GRIHA are used in India. These provide credits for the buildings upon satisfying criteria designed to address specific environmental impacts inherent in building design and construction. Developing countries are observed to give less priority to social and economic aspects when compared with developed countries (Olawumi et al., 2020; Zarghami and Fatourehchi, 2020). These aspects should be addressed even before the environmental aspects are addressed. If the assessment tools are to be practical and valid, they must take into account national, regional, and cultural diversity (Onat et al., 2017; Kaur and Garg, 2019). It is observed that Building Research Establishment's Environmental Assessment Method (BREEAM), LEED, and Hong Kong Building Environmental Assessment Method (HK-BEAM) do not consider the economic aspect for assessment (López et al., 2019; Baiz and Hoskara, 2021; Ascione et al., 2022). Some sustainable buildings can be economically feasible and ignoring this can act as an obstacle to sustainable development. These green building assessment tools aim to identify and assess different sustainable practices that can be involved at all the stages of the building life cycle (Vyas and Jha, 2018).

Building assessment tools mainly consider the environmental impact and do not adequately consider the economic and social aspects of a building. Sustainable construction has to maintain a proper balance between environmental impact along with economic development and social improvement. Sustainability is like a three-legged stool where each leg symbolizes the social, economic, and environmental aspects. Missing any of them will cause imbalance and unsteadiness in the overall building performance assessment since all the three components are interlinked (Robert et al., 2002). Therefore, these assessment tools should also take into account the economic and social aspects of a building. Impact on community, health and safety issues, risk management, security measures, and so on are vital factors to consider when environmentally sustainable buildings are planned. Hence these tools are just environmental assessment tools but not sustainable assessment tools.

Sustainable impacts (social, environmental, and economic) in project development are different at every phase of a building. Therefore, a model is required to assess the building performance at various phases of the building from the initial to the end-of-life stage of construction. Thus, the project development phase of a building can be classified into various processes (Sev, 2011). This strengthens the point of assessing the performance of the building in all the phases (Kaatz et al., 2006). This helps to allocate resources to the stages that have additional noteworthy impacts.

1.3 PROBLEM IDENTIFICATION

The building assessment tools recognized that economic knowledge was insufficient and also accredited that a good lifestyle and well-being of society are important. This gave rise to some sustainability indicators called Triple Bottom Line (TBL)of sustainability (Chandratilake and Dias, 2013).In order to attain sustainable development, importance is to be given to TBL impacts namely, environmental, economical, and social aspects of the building form in association with the inception to completion phase (Al-Qawasmi, 2019). Environmental sustainability provides the opportunity to use natural resources without depleting them. Economic sustainability considers the economic impact on the society and social sustainability provides a good quality of lifestyle (Bernardi et al., 2017). These three concepts are considered to be the three pillars of sustainability (Brundtland Report, 1987). In this regard, the stakeholders can have an overview of the most relevant characteristics to implement the concept of green building in construction (Vyas et al., 2019b). The objective of designing a green building that is cost-effective and energy-efficient requires developing a model that ensures the sustainability pillars in all stages of building. A framework comprising interdisciplinary research, involvement of stakeholders, and performance indicators pertaining to regional conditions is useful for life cycle sustainability assessment (Janjua et al., 2020).

Building assessment tools are being used worldwide, but the regional adaptation of the tools in developing countries is concerning. This is because the assessment indicators are distinct at different locations. Therefore, the assessment indicators should address all the varieties, including national, regional, and cultural adaptations (Sev, 2011). Building Assessment Tools (SATs) such as LEED – India and GRIHA are used in the Indian construction sector. However, these tools hardly satisfy all the major conditions with respect to sustainability. To address these problems, the present study aims to develop a Building Performance Score (BPS) model for every phase in the building development considering social, environmental, and economic aspects.

Though some of the previous research has already covered the economic and social criteria in the assessment process, few of them have put it in each phase of building project during the whole life cycle. As suggested in the literature, economic, social, and environmental impacts associated with project development will vary at different stages throughout its life cycle (Shen et al., 2002; Ding and Shen 2010). Consequently, assessing and incorporating sustainability performance into building life cycle process from initial stage to end-of life is essential. A comprehensive model is needed to provide an alternative approach for assessing the feasibility of a built project during its life cycle in attaining sustainable development. It reveals the sustainability performance at various stages of the development so that resources can be dedicated to the stages that have the most significant impacts.

Performance at every stage of the building along with performance of the whole building is considered for the assessment. The purpose of doing this is that the stakeholders can have different interests in the field of construction. The occupants give importance to a comfortable living space; the building industry wants to minimize the project cost and the designer's interest is in aesthetics. These indicators have different influences at every stage in the life cycle of a building. When two buildings are considered for the performance assessment, they can have the same score when a complete building performance assessment is done but they might perform differently at different stages. Hence, proper comparison cannot be done without considering each phase of the analysis. Assessing the building's performance at every stage will help the stakeholders in understanding the requirements to enhance the performance of the building.

Some of the indicators influence the sustainability performance in different stages of the building life cycle. One of the indicators might enhance the environmental effect in one of the stages but this might not be the case for economic impact. Therefore, a tool that assesses the building performance on an overall basis cannot satisfy all the stakeholders and this makes assessment process at every stage in building life cycle necessary. This model serves as a guideline in the decision-making process to identify the areas for improvement and to achieve sustainable development. A complete building performance assessment is done at every stage in this model.

To sum up, the major research gaps are:

- The current environmental assessment tools are criticized as being ineffective and inefficient in addressing the sustainability issues with regards to the increasing attention paid to building performance.
- Sustainable building assessment have strong regional differences, and the application of the international tools in China will still have some shortcomings.
- India’s own tools – LEED – India and GRIHA are criticized for not sufficiently taking into consideration economic and social issues in building life cycle.
- Life cycle has not received sufficient attention in building assessment process.

1.4 RESEARCH OBJECTIVES

The objectives of this research are to develop a decision-making model incorporating sustainable aspects for the building performance assessment. The research objectives are meant to achieve the aim of the study.

- To identify the gap in the existing building assessment tools in consideration of different phases of construction and the building process.
- To develop a comprehensive building performance model that incorporates the sustainable indicators pertaining to the triple bottom line of sustainability of building process.
- To assess the sustainability of buildings using the comprehensive building performance assessment model and validate it in the present scenario.

1.5 SCOPE OF THE WORK

India is witnessing a boom in the real estate and construction sector which is growing at the rate of 9% against the world average of 5.5% and contributes on an average 6.5% to the GDP (Sharma, 2018). Urbanization is increasing at a galloping rate and it is estimated that two-third of the world population will be living in cities by 2050. Further India is expected to be the most populous country by 2028 according to United Nations Report and this will put tremendous pressure on energy demand (Sharma, 2018).The building structure itself is heavily taken into account in the assessment of the building's performance. However, if the building itself weighed heavily in the evaluation, this domain needs reformation. Building's impact on the environment must be measured, managed, and reduced at local, regional, and global levels. For the purpose of this study, the evaluation of building performance takes place on a nationwide scale. With a national scope in mind, environmental, economic, and social impacts will be assessed. Climate and economic circumstances in India differ from area to region due to the country's immense size and diversity. In this way, this research can serve as a starting point for other studies in the future. When the model is applied to a different location, it must be modified to meet the local requirements.

Around 30% of the power consumed in residential, commercial, and public structures can be conserved through better insulation, well-regulated ventilation and air conditioning systems, and more efficient heating technologies (Bhatt and Macwan, 2012; 2016). With a rapid increase in population and urbanization, the energy demands are also reaching heights in India (Gandhi et al. 2020; Kameswararao and Manideep 2017). Bureau of Energy Efficiency, India has estimated the commercial sector energy consumption for the year 2030 to be 2.648 EJ (BEE, 2020) and a total floor area estimation by ECOIII till 2030 to be 1090 m^2 under the commercial sector (Kumaret al. 2010). Growth in floor area per year directly indicates the growth in high energy demand that ultimately leads to high emission rates. Increasing trends of the energy consumption in the country per year with an exorbitant incremental rate indicate the need for transformation from fossil fuel to a renewable source of energy for electricity generation along with conservation of non-renewable resources and reduction in carbon emissions.

Commercial and residential buildings differ from a wide range of perspectives. For example, energy consumption and carbon emissions are high in commercial building projects. The energy consumption for any building in its complete life cycle is classified as embodied energy and operational energy (Huang et al., 2018), and the consumption is estimated to be 10-20% and 80-90% respectively for conventional buildings (Ramesh et al., 2010; Toosi et al., 2020). However, several research studies have shown that for low-energy or green buildings, this amount is less (Karimpour et al., 2014), and taking account of Net Zero Energy Building (NZEB), this value could be reduced to zero (Asdrubali et al., 2019). Furthermore, these conventional buildings account for 40% of the world's energy requirement and 44% of society's material use (Vyas and Jha, 2018). As a result, when evaluating perceptions of energy-saving, decreasing carbon emissions, and achieving sustainability, these structures must be prioritized. Hence only commercial projects are considered for this study as these buildings seem to be more environmentally significant in comparison to residential developments (Sharma et al., 2018). The emergence of huge commercial structures in India during the last few decades has been exceptional. These modern constructions are always accompanied by enormous curtain walls and artificial lights, all of which consume a substantial amount of energy. Further, the energy consumption and carbon emission are estimated to be more in the case of commercial buildings as compared to residential types (Jiang and Tovey, 2009; Sharma et al., 2018; Zhao et al., 2012). Commercial buildings should be more prioritized while considering overall energy conservation and carbon reduction within the building sector for achieving sustainability. As a result, the long-term performance of commercial buildings is the focus of our study. Therefore, this study is more focused toward performance of buildings on all aspects of sustainability.

1.6 SIGNIFICANCE OF THE RESEARCH

As mentioned earlier, there are various drawbacks in the present building assessment tools, requiring further improvements like the involvement of economic and social aspects in assessment tools. This contributes to addressing sustainability issues and helps take sustainability into account in decision-making in the construction sector.

This study will consider all building life cycle stages to incorporate sustainability concepts into each phase of the building life cycle. The assessment model developed from the study can be used as a replacement for the present assessment tool to have a better building performance assessment concerning sustainability.

1.7 STRUCTURE OF THESIS

Chapter 1: Introduction - This chapter explains the cause and motive of commissioning the research study. The background of the study is also discussed, and the gaps identified in the same field are also discussed. The aim and objective of the research are also expressed.

Chapter 2: Literature Review - This chapter presents the literature study on sustainability in the context of environmental, economic, and social matters. This also provides an overview of sustainable buildings and building assessment tools with the building process and their life cycle performance reported by the various researchers on building in India and abroad.

Chapter 3: Research Methodology - The research design and overall study methodology are discussed in this chapter and also a detailed explanation is provided as to how the research is carried out. A questionnaire survey is conducted along with semi-structured interviews for data collection. Case studies are selected to verify the model.

Chapter 4: Data Collection, Analysis and Discussion - This chapter will describe the data collecting method as well as the findings of data analysis. The findings were examined in light of the preceding chapter of literature review. The outcomes of data analysis are reviewed to draw critical inferences for the development of the Building Performance Score (BPS) Model.

Chapter 5: Development of Building Performance Score (BPS) Model - This chapter proposes a model for measuring building sustainability performance using a review of the literature and a survey of the industry. The method of developing indicators is described, followed by a comprehensive examination of these indicators. Indicators will be evaluated using quantitative and qualitative techniques. The relative importance of each indicator is then determined. The AHP technique is used to give the relevance of the indicators in relation to one another.

Chapter 6: Case Study and Model Verification - After the model is developed for building performance assessment, case studies are utilized for model validation. The complete process of analysis of the case study using the model is discussed. The performance in each case study at every phase and also the overall performance of the building are analyzed. The result obtained from the BPS model is compared with LEED results for further discussion.

Chapter 7: Conclusions and Recommendations - This chapter summarizes the research findings. The research aims and objectives are discussed, and the final model verification results are discussed. The outcome of the BPS model and further contributions to knowledge are explained. The limitations of the research and future research recommendations are also discussed.

1.8 SUMMARY

This chapter discussed the rationale for this study. It begins with an overview of the research approach. The research issues and questions are identified, and then the study objectives are defined. Additionally, it emphasized the significance of this research, as well as the necessity and practicality of doing this research. This thesis contains seven chapters that cover all elements of this study. The structure of the thesis is also given here. The thesis structure is also given here. The chapter that follows will go over a thorough literature review on this topic.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, a detailed review of literature is presented that covers the concept of sustainability and Triple Bottom Line (TBL) approaches. Considering this, the concept of the TBL was developed by assessing the environmental, economic, and social factors and this concept is used in the construction sector. Various assessment approaches to analyze sustainable aspects are reviewed in this chapter. Sustainable construction has gained extensive prominence among the researchers and general public for the past many years. Sustainability signifies the relationship between social, environmental, and economic aspects. The assessment approaches environmental, economic, and social elements are reviewed in this chapter. The Life Cycle Assessment (LCA) and consumer-based approaches are discussed in the environmental assessment. The Life Cycle Costing (LCC) and various types of cost estimation methods are discussed in the economic assessment. Social Impact Assessment (SIA), social footprint, and other approaches to social assessment are reviewed. In the present study, the literature review is categorized into three parts, namely,

- Sustainability and triple bottom line.
- Sustainable building and sustainable assessment.
- Building process and building life cycle performance.

2.2 SUSTAINABILITY AND TRIPLE BOTTOM LINE APPROACHES

One way of achieving sustainability in the construction industry is by building only ‘green’ buildings (Vyas and Jha, 2016). A green building would optimize the consumption of electricity, water, wastage, and the demand for sustainable building materials during the building process. Green buildings can minimize the consumption of non-renewable resources (CURC, 2007; Vyas and Jha, 2016; Vyas and Jha, 2017, Lau and Hashim, 2019; Dell’Anna et al., 2020). They also maximize the efficiency of the whole building process by increasing recycling and by using more resources that are renewable. In turn, they reduce the adverse impacts of buildings on the environment by implementing various criteria like the improved location of sites, design optimization, construction processes, operation and maintenance processes (GRIHA, 2007; Ding and Shen, 2010; IGBC, 2011; Akadiri et al., 2012; Liu et al., 2013; LEED, 2015; Vyas and Jha, 2017; Dell'Anna et al., 2020). The frame work of sustainability conceptualizes the important indicators of sustainable development and the inter-linkages between these indicators. It was recognized that economic knowledge was insufficient in conventional tools and also accredited that a good lifestyle and well-being of society is important. This gave rise to some sustainability indicators called Triple Bottom Line (TBL) of sustainability (Chandratilake and Dias, 2013; Cruz et al., 2019). Therefore, momentum has gained to develop and design green buildings that are cost-effective and focus on encompassing all the sustainability tools in the life cycle of a building (Ding and Shen, 2010; Liu et al., 2013).

The existing building assessment tools are considered scanty in presenting a sustainable model for the construction industry. Most of the existing tools give importance to assessing some predetermined objectives and they do not give required importance to the social and economic aspects of constructing a building in a habitat (Sinou et al., 2006; Ding, 2008; Bonyad et al., 2018). Sustainability needs a three-legged approach with each leg giving importance to the social, economic, and environmental impact of the building. Whenever one of the three legs of the three-legged approach is missed, it will cause imbalance and unsteadiness in the overall building performance assessment; since all the three legs are interdependent (Mesthrige and Kwong, 2018). Many researchers expressed that the existing assessment tools for green building cannot be adopted for all the regions (Agrawal and Tiwari, 2010; Alexeew et al., 2015; Vyas et al., 2019b). Therefore, an attempt is made in this study to identify various indicators pertaining to the triple bottom line of sustainability, and further the building performance score model is developed by including various building stages and the respective indicators in each stage.

2.2.1 Triple bottom line assessment

This section deals with the discussion of three pillars for sustainability which comprises of environmental, economic, and social assessment approaches.

2.2.1.1 Environmental assessment approaches

Increasing focus on sustainable aspects of building performance has led to the development of various approaches to evaluating the impact on the environment. LCA is a commonly used approach for the assessment in construction industry (Ortiz et al., 2009; Bilec et al., 2010). LCA is a tool adopted for environmental performance analysis which is deemed as an approach of "cradle to grave". This assessment tool focuses on products, materials, or processes for their environmental performance throughout the complete life cycle in a systematic way. The impact from the procurement stage of raw materials up to the final stage of project disposal is taken into consideration.

LCA approach is gaining a lot of importance in the present context. Various studies are conducted to evaluate the complete building and its systems and the construction process using the LCA approach. Table 2.1 gives an insight into LCA approaches to evaluate the building performance.

Table 2.1: Summary of LCA approaches for the assessment of building performance

Methodology	Research Study	Major Findings	References
Process – based LCA approach	Assessment of energy usage in the complete life cycle of building, emission of GHG and cost incurred for a residential building in Michigan during construction, operation and demolition stage.	The operation stage contributes to 91% of total life cycle consumption of energy over 50 years building life.	Keoleian et al., 2001
Process – based LCA approach	Assessment of the effects of concrete framed office building on the environment in Finland.	The major impact on environment was due to the electricity and heating use during material production and the operation stage of building.	Junnila and Horvath, 2003
Process – based LCA approach	Considering two new office buildings for evaluation in US and Europe throughout the life cycle of building.	The operation stage contributes to 70% of energy consumption. Major contribution in emission is during the materials production and maintenance period, especially in USA.	Junnila et al., 2006
Process – based LCA approach	Assessing the design of three residential buildings in Switzerland.	This has a direct influence on the environment which can be reduced by implementing the use of renewable sources of energy and by providing better insulation systems.	Citherlet and Defaux, 2007
Process – based LCA approach	A single storey residential building with different exterior wall systems is considered to evaluate its impact on environment.	The operation stage contributes to 94% of total energy consumption.	Kahhat et al., 2009
EIO (Economic Input –Output) - LCA	Assessment of three residential buildings in Pennsylvania, Texas and Michigan, USA.	The operation stage contributes over 90% of energy usage, depletion of fossil fuel and severe impact on human health conditions. This also contributes to about 50% of global warming condition and air pollution.	Franco, 2004

EIO (Economic Input –Output) - LCA	Considering a green roof and built-up roof for comparing economic and environmental effects.	A green roof produces three times more pollutants when compared to built-up roof. When compared with green roof, built-up roof produces three times more pollutant during operation and maintenance stage. Considering the complete life cycle of building, the built-up roof accounts for 46% of pollutant emissions when compared with the green roof over a period of 45 years of life span.	Muga et al., 2008
Hybrid LCA	Assessing the impact on environment of steel and concrete framed buildings.	The operation stage has major impact on energy use and this can be reduced by implementing energy – efficient design. Whereas the impact of construction phase on energy use is minimal (0.4 – 11%) and the maintenance stage and demolition stage also have minimal impact on energy use.	Guggemos and Horvath, 2005a
Hybrid LCA	Evaluating the impact of construction stage of commercial buildings on the environment in California.	Use of machinery has about 50% impact on environment whereas temporary construction materials are the second largest contributor to the impact on the environment.	Guggemos and Horvath, 2005b
Hybrid LCA	Evaluating the impact of construction stage of precast parking garbage in Pittsburgh, USA on the environment.	Transportation is the prime influencer in most of the categories.	Bilec et al., 2006
Hybrid LCA	Evaluating the impact of construction stage of commercial buildings on the environment.	Though construction stage is not considered as important as the operation stage it has significant importance as other stages in the building life cycle and emissions are also vital in construction stage.	Bilec et al., 2010

As shown in Table 2.1, some of them focus on just one or more development phases of building. For instance, Keoleian et al., (2001) focus on the construction, operation, and demolition stage in the building development phase for the assessment of energy consumption and emission of greenhouse gases, whereas Guggemos and Horvath (2005b) focuses on the impact of a commercial building during its construction stage on the environment. Bilec et al., (2010) also studied the effect of a commercial building on the environment during its construction stage and stated that construction stage holds equal importance as the other stages involved in the assessment.

Many other researchers focused on all the development phases of the building. For instance, Junnila et al., (2006) conducted an assessment evaluation for two new offices throughout the life cycle of the building from inception to the demolition stage. Guggemos and Horvath (2005a) studied the impact of steel and concrete framed structures on the environment and it was found that impact during the operation stage was more than in the construction stage of the life cycle. The impact during the maintenance and demolition stage was found to be minimal.

Bilec et al., (2010) research study to understand the impact on the environment during the construction stage in the life cycle of a commercial building explains the approach of hybrid LCA method. This method is basically a combination of both the process-based approach and the Economic Input-Output LCA (EIO– LCA) approach. The construction model for this approach is generated in the software Analytica. It includes both the process involved in the construction and also detailed modeling of construction equipment combustion. The main reason for the wide application of this method in construction industry is that this method aims to advance the time and cost factors associated with the process-based approach and henceforth develop a comprehensive boundary (Guggemos and Horvath 2005b; a).

2.2.1.2 Economic assessment approaches

Presently, the construction sector is facing many challenges such as fulfilling the requirements of society to achieve sustainability and aiming to reduce the cost incurred in the construction and operation phase of the building. Reducing the initial cost can be accomplished by using appropriate building techniques or simplifying the structure. But this alone is not sufficient to reduce the cost. In the forty-year life span of a building, operating and maintenance expenses will contribute to 55% of the overall total project cost of the building and in developed countries, it is observed that repair and maintenance account for 60% of the total cost of the building (Bull, 1993). From this, it is evident that along with designing durable and economic buildings, proper financial planning and scheduling for repair and maintenance are also necessary.

LCC analysis is a way to identify a better and more detailed picture of the cost of building life cycle (Sterner, 2002). A comparative assessment of cost over a definite period of time can be done by using the LCC technique. All the economic factors are considered in ISO-15686, including initial and future operational costs (Pelzeter, 2007). All the costs such as capital, operation, maintenance and replacement costs are put up in such a way that can be compared and a single picture which shows that all of these costs incur at different phases in the building life cycle. Because of this, a comparison between different design options can be made and the design with optimum value can be selected to invest in.

Other methodologies like Total Cost Assessment (TCA) and Full Cost Accounting (FCA) provide a better insight into cost other than LCC. In TCA methodology, a broader range of direct, indirect, and contingent costs is considered. A broader range that includes the environmental and social costs of the building is considered in the FCA methodology (Spitzer et al., 1993).

Many researchers have conducted studies in this field for many years. In addition to the methodologies mentioned above, certain methodologies are framed by the researchers such as Full Cost Pricing (FCP), Life Cycle Cost Accounting (LCCA), Whole Life Costing (WLC), and Life Cycle Accounting (LCA*) (Spitzer et al., 1993; EPA, 1993; Bennett and James, 1997; Clift and Bourke, 1999). A comparison of all these approaches for economic assessment since the last century is shown in Table 2.2. The objectives of these methods are similar though they differ in their names and descriptions and cost estimation of the project is done from the life cycle perspective of the building.

Table 2.2: Comparison of economic assessment approaches.

Types	Description	Reference
Life cycle costing (LCC)	This is a technique that considers all the economic factors in terms of both initial and future cost and over a definite period of time comparative cost assessment is done.	ISO 15686
Total cost assessment (TCA)	Complete and long-term cost assessment of investment with internal cost and savings.	Spitzer et al., 1993
Full cost accounting (FCA)	Complete cost identification and quantification during the complete life cycle of the product, process, or service.	Spitzer et al., 1993
Full cost pricing (FCP)	This is a term similar to FCA or LCC	Spitzer et al., 1993
Life cycle accounting (LCA)	In this method assessment of costs incurred specifically to product during the life cycle period of the building is carried out.	EPA, 1993
Life cycle cost assessment (LCCA)	Identification of environmental effects and measuring its monetary value in order to analyze the life cycle cost of product or service in a systematic process.	Bennett and James, 1997
Whole life costing (WLC)	This is similar to TCA or LCC which is defined more systematically by considering all the probable costs and returns linked with procurement and possession of the asset.	Clift and Bourke, 1999

In order to evaluate the building performance considering the project development cycle, the LCC method is used to assess the building performance from an economic point of view. The soundness and effectiveness of LCC method make this method suitable to be used within construction industry for practical application and implementation (Olubodum et al., 2010). This methodology is being used in recent times in order to assess the economic performance of the building. It is evident that estimates of subjects from the LCC method comprise all the cost elements and converts it to the cost at present and along with this three critical areas must be examined in order for the LCC to be accomplished (Olubodum et al., 2010):

- Initially, the capital cost which includes operation and maintenance costs along with replacement and disposal costs has to be obtained.
- Further, while making assumptions or predictions, it should be noted that the life span is to be considered. This will beneficial for determining the operational period and frequency of maintenance or replacements of the required elements. Finally, future market conditions such as risk involved, inflation, and interest rates are required to be considered.

Questions regarding the beneficiary of LCC calculations for decision-making purposes are raised because of the concern regarding the deficiency of satisfactory cost data and uncertainties (Olubodum et al., 2010; Sterner, 2000). In most cases, a design with a low capital cost is selected without considering the operation and maintenance costs involved in the project (Bull, 1993). Problems and difficulty in estimating project life cycle costs are found to be an additional obstacle. From the above discussion, it is evident that for accurate LCC calculation satisfactory cost data is essential along with standards that are acceptable in the industry in order to define the internal process system and life cycle behavior of the facilities (Abraham and Dickinson, 1998). Sometimes inadequate capability to anticipate the consequences that might occur in the future and limitations of information regarding historical costs will result in difficulty in receiving cost data (Sterner, 2000). When there are uncertainties in the calculation for some of the parameters, estimation is essential and this is considered to be the reason for inaccuracy.

Environmental LCC and societal LCC are the other types of LCC methods identified in the process of LCC development. Assessment of all the costs linked with the life cycle of the product is the conventional LCC method which is directly covered by the main user or producer. Considering various stages in the complete life cycle, conventional LCC relies completely on economic evaluation to a larger extent. One or more factors in the life cycle of the product cover environmental LCC assessment including externalities in future decisions that are foreseen as internalized (Rebitzer and Hunkeler, 2003). Societal LCC is an assessment at present or in long – term future which is covered by the society. Also, societal LCC includes external cost assessment along with environmental LCC assessment.

The three LCC methods are similar to the three environmental approaches which are LCC, TCA, and FCA in terms of their definitions. When these LCC methods are developed further, this covers additional concepts such as internal and external cost which corresponds to TCA and FCA definitions. The different types and the number of costs included in the analysis form a major difference between conventional and other two LCC methods where the costs are considered as contingency costs and also as environmental and social costs.

Along with this, there exists a lot of criticism against the traditional LCC method. The reasons such as insufficient access to required performance data, absence of standard formats, and universal methods are found to be the limitations when the LCC method is used in construction industry (Cole and Sterner, 2000). Though various limitations are found in LCC method, it is still considered to be a "valuable approach for comparing alternative building designs" (Cole and Sterner, 2000). Supporting this statement, Kirkhan et al., (2002) stated that LCC method is a valuable tool in order to assess construction facilities in terms of economic efficiency.

2.2.1.3 Social assessment approaches

Along with the other two assessment approaches, Social Assessment Approach acts as a vital component of the Triple Bottom Line approach. Social impacts were very much ignored as people believed that this deals only with the cost and cannot be measured and this would also hamper the progress of the project development. They also believed that considering these impacts was not beneficial (Burdge, 1987). This is acknowledged as the weakest pillar amongst the pillars of sustainable development and this is because of inadequate analytical and theoretical information and knowledge (Labuschagne and Brent, 2005). Social Impact Assessment (SIA) has been developed as a background for social assessment since the early 1970s. Additional social impact assessment approaches have been developed since then.

According to Burdge (1987), the SIA approach provides an efficient method to carry out proceedings and plan for these impacts before the development of the project. As the concept of SIA is developing progressively, data collection and evaluation in a project or at the community level is possible, and social impacts measurement becomes dependable. The duration, amount, and sequence of these impacts are to be assessed and for this various SIA models are established. Based on research, developed a model to be included in the inception phase to evaluate the social impacts. It ensures that social impact concerns are included during the initial planning stages and not after the decision has been made. SIA is associated with increasing the project's cost, but it is also found that it saves money in the long run.

SIA has been defined as micro, meso, and macro in the International Handbook of Social Impact Assessment (Becker and Vanclay, 2003). These focus on individuals and their behavior, organizations or social networks, and national and international wide respectively. These impacts are different at each stage as not all the consequences will occur at all the stages at the project level. Both qualitative and quantitative factors are included in the information and data acquired throughout this procedure. The SIA method identifies, quantifies, and interprets both direct and indirect social impacts. This provides information to the community leaders and project planners regarding the benefits and associated costs of social impacts. But measuring the procedure for every project is found to be difficult. The author conducted a study describing the involvement of social impact in the planning process and thereby explaining the SIA model and also finds methods to measure the same. The author also stated that recognizing and estimating the social impacts that occur with each of the projects are the significant difficulties encountered in the application of the SIA process.

SIA does not account for the beneficial impacts of the development and considers the impacts on individuals rather than the whole society (Becker, 2001). Further, Vanclay (2009) stated that comparable to EIA, SIA is destined to be appropriate at policy and project levels, but it has stuck just at the project level in practice and experience. All these limitations against SIA explain that this assessment approach can be combined with other assessment approaches to include the environmental and economic concepts in the assessment. In order to consider SIA as a valuable assessment tool, it has to be used in combination with environmental and economic impact assessments.

2.3 SUSTAINABLE BUILDING AND SUSTAINABLE ASSESSMENT

The construction industry in India is one of the most significant economic activities and this sector is growing at an average rate of 9.5% as compared to the global average of 5% (Dutta and Sengupta, 2014). As the sector is multiplying, preserving the environment poses a host of challenges. Buildings have significant environmental impacts over their entire life cycle. Resources such as ground cover, forests, water, and energy are depleted to give way to buildings. The water consumption of these individuals is significant during the building and use phases (for occupants, cooling, and landscaping). Per capita, water usage in 1990 amounted to 2464 m^3 per year, but by 2025 it is virtually certain to be in the class of stresses, with less than 1700 m^3 per year, with an anticipated population of 1.4 billion (Vyas and Jha, 2016). Management of construction and demolition waste and solid waste generated by occupants of buildings poses another major challenge that needs urgent attention.

The Central Pollution Control Board (CPCB) has estimated that the current volume of solid waste creation in India is 48 million tonnes per year, with the construction industry accounting for 25% of the garbage. The handling of such a large volume of trash places great strain on the solid waste management system. Furthermore, the country's metropolitan regions create around 42 Million Metric Tonnes (MMT) of solid garbage each day (Kumar and Agrawal, 2020). Most metropolitan areas lack adequate solid waste segregation, management, and treatment facilities. At the moment, municipal solid waste is rarely separated at the source. At the macro level, increasing urbanization is causing an uncontrollable 'heat island effect'. Vegetation and tree cover give way to sidewalks, buildings, and other constructions in urban environments, removing the cooling benefit given by vegetation through both shade and evapo-transpiration.

The primary source of environmental pollution is believed to originate in the construction industry (Vyas and Jha, 2016). These include energy, resource use, and trash generation throughout the building's life cycle, which are responsible for environmental problems. To achieve the goal of SD, sustainable performance is critical. Since sustainable performance is gaining much importance, various tools have been developed to assess building performance. These tools serve as a support in the initiation and designing of sustainable buildings. It contributes to raising awareness about the notion of sustainability in the building sector. This chapter deals with sustainable buildings and various tools developed to assess the performance of the buildings. A Green Building Rating System is an assessment tool that assesses a building's performance throughout its development cycle (Vyas and Jha, 2016). It often includes a set of pre-determined criteria linked to design, building, and operation, with pre-assigned points and defined benchmarks, as well as quantifiable goals or objectives.

Green building rating systems provide a functional framework for evaluating building environmental performance and incorporating sustainable development into building and construction processes (Vyas and Jha, 2016). It is used as a design tool for setting sustainable design priorities and goals, developing appropriate sustainable design strategies, and determining performance measures. These measures guide the sustainable design and decision-making processes. Economic and environmental factors require attention in order to achieve the concept of sustainable development. Hence, prominence towards a more sustainable approach to green building design and cost-effectiveness has gained momentum. The practice of efficiently using resources such as energy, water, materials, etc is known as green building or sustainable design (Vyas and Jha, 2016), and adopting such practices will significantly reduce the impact on our environment and human health. This concept extends beyond the walls of buildings and includes site planning, community planning, and land use planning issues.

2.3.1 Green building rating system in India

There are two rating systems in India namely LEED - INDIA and GRIHA developed and are being used in the construction industry.

2.3.1.1 Leadership in Energy and Environmental Design (LEED) - India

IGBC took the initiative of developing LEED - India guidelines by modifying LEED (USA) to suit the Indian context. The first LEED-India rating programmed was launched during the Green Building Congress Conference in October 2006. LEED India had set some guidelines for the green rating of commercial and office spaces and they are:

LEED India for New Construction (NC) 2 and Major Renovations – for guidance to design, build, and maintain green commercial buildings. In LEED India (NC) rating frame work, the various guidelines are presented under six categories.

a. Sustainable building sites (13 possible points)
b. The efficiency of water management (6 possible points)
c. The atmosphere and energy (17 possible points)
d. The usage of resources and material (13 possible points)
e. Quality of the environment inside the building (15 possible points)
f. The processes of innovation and design (5 possible points)

Thus, the total maximum points count to 69 points. The rating of the building depending on the credit points is as follows.

- Certified – 26 to 32 points
- Silver – 33 to 38 points
- Gold – 39 to 51 points
- Platinum – 52 to 69 points

LEED is a globally recognized certification agency, which is considered a benchmark of reputation used to measure sustainable models in building and design. Indian Core Committee set up LEED-India (2011) for new construction and major renovations and focuses on designing a suitable rating system for the Indian scenario. The committee members consist of architects, engineers, developers, manufacturers, building owners, and industry representatives. This array of people from all the construction market sectors adds depth to the whole procedure and the end product. The LEED for India Green Building Rating System is a widely agreed consensus in the industry. This consensus is based on technology that is proven and world-class. This consensus provides a clear standard for what makes up a ‘green building’. This assessment is done based on studying the environmental performance of the building during its whole life cycle.

However, the previous version of LEED-India has been modified and the new rating system presently used to assess the performance of the buildings consists of various guidelines presented under the following aspects.

1. Sustainable building sites (28 possible points)
2. The efficiency of water management (10 possible points)
3. The atmosphere and energy (37 possible points)
4. The usage of resources and material (14 possible points)
5. Quality of the environment inside the building (15 possible points)
6. The processes of innovation and design (6 possible points)
7. Priorities of the region concerned (4 possible points)

Thus, the guidelines provide a maximum of 100 points under the five categories and 10 points under the last two categories. The rating of a building depending on the credit points is as follows.

- Certified – 40 to 49 points
- Silver – 50 to 59 points
- Gold – 60 to 79 points
- Platinum – 80 and above

These seven parameters decide the sustainability of a building when the five environmental categories do not cover the study. Another feature of the bonus point in LEED for India is the inclusion of provincial conditions in assessing the building industry’s best sustainable composition and processes. It strikes a balance among the current and emerging practices and also the budding theories. This is a system that is based on performance. Here, the credit points are allotted to satisfy the given criteria designed to address the precise impacts on the environment included in the construction process. On the basis of the cumulative credits earned, various levels of certification are awarded to the respective buildings. The ratings of LEED India are based on 100 points. Six of them are on innovation and four of them are based on regional priority issues.

2.3.1.2 Green Rating Assessment for Integrated Habitat (GRIHA)

Green Rating Assessment for Integrated Habitat GRIHA is developed by the Ministry of New and Renewable Energy (MNRE) and also by the federal Indian government's own rating system (Smith, 2015). In this system, a building is rated based on a unique three-tier system. The application for the inspection of the building is accepted online. After that, a team of professionals will visit the building for evaluation. This system has 34 criteria classified into four different sections as given below:

1. The selection of the site and planning
2. Conservation of resources and their efficient utilization.
3. Operation and maintenance of the building
4. Innovation

Since 2007, the GRIHA has implemented a vision for green buildings through a rating system designed for the Indian construction industry. In order to reduce the demand for conventional energy and to optimize the performance of the energy on an optimal level, the GRIHA encourages an optimal building design. The comfort limits are specified in order to address the energy efficiency criteria. This system mainly was meant for air-conditioned and partly air-conditioned buildings. This system addresses the environmental concerns of the country and it also takes care of the regional climatic conditions to take care of the indigenous solutions. This system is suitable for not only residential buildings but also for commercial and institutional buildings. This system facilitates the practices for all the existing provisions of the Indian building codes by integrating them into the new system. The buildings are awarded various levels of certification from one star to five stars. This is given based on credit points earned as a percentage. The minimum point required is 50. The GRIHA ratings are given according to the following format:

- 50 to 60 points: One Star
- 61 to 70 points: Two star
- 71 to 80 points: Three star
- 81 to 90 points: Four star
- 91 to 100 points: Five star

The critical and prominent stages of the life cycle have been compared by various rating tools in India. Following are the highlights of the consideration of LEED-India and GRIHA in assessing the green building as shown in Table 2.3.

Table 2.3: Comparative Assessment of Building Assessment Tools

Sl. No.	Category	LEED		GRIHA	
		Applicability	Points available	Applicability	Points available
1.	**MANAGEMENT/SUSTAINABLE SITE**				
a)	Site selection/reuse of land/sustainable construction	Y	1	Y	1
b)	Preserve and protect the landscape during construction/ preserve top soil / existing vegetation	Y	1	Y	5
c)	Soil conservation/top soil laying and stabilization/hard landscaping and boundary protection	N	0	Y	2
d)	Brownfield re-development	Y	1	N	0
e)	Design to include existing site feature / maximum open space	Y	2	Y	4
f)	Building and site operation and maintenance	N	0	Y	2
g)	Universal design	N	0	N	0
h)	Integrated design approach	N	0	N	0
i)	Passive architecture	N	0	N	0
j)	Project management	N	0	N	0
k)	Green building guidelines	N	0	N	0
2.	**ENERGY/ENERGY EFFICIENCY/ENERGY USE**				
a)	Renewable energy utilization	Y	7	Y	8
b)	Minimum energy performance/Optimize energy performance	Y	19	Y	16

c)	Fundamental building commission/ Measurement and verification/ Energy monitoring/Metering and monitoring	Y	4	Y	0
d)	Ozone depletion	N	0	Y	1
e)	Additional commissioning	Y	0	Y	1
f)	Energy Improvement/Green power	Y	2	Y	3
3.	**INDOOR ENVIRONMENTAL QUALITY**				
a)	Optimize building design to reduce the conventional energy demand/ Naturally ventilated design/Localized ventilation	Y	1	Y	8
b)	Day lighting and views/ Visual comfort/ Day lighting/ External Views /Artificial lighting minimization/Interior lighting normally specify	Y	2	Y	3
c)	Reduce heat island effects/ Thermal comfort/ Thermal insulation/ Thermal performance of building	Y	5	N	0
d)	Low emitting/ Indoor chemical and pollutant source control/ CO_2 monitoring and control/ Hazardous materials/ Indoor air pollutants/ ETS control/ tobacco and smoke control	Y	6	Y	3
f)	Minimize ozone depleting substance/ HCFC and CFC free HVAC/ Low and zero carbon technology/ construction indoor air quality management plan	Y	4	Y	1
g)	Acceptable indoor and outdoor noise levels/ Acoustic performance/ Background noise	N	0	Y	2
4.	**HEALTH AND WELL BEING**				
a)	Minimum level of sanitation/Safety facilities for construction workers	N	0	Y	2
b)	Reduce air pollution during construction	N	0	Y	2
c)	Occupant wellbeing facilities	N	0	N	0
5.	**RECYCLE/RECHARGE AND REUSE OF WATER**				
a)	Water consumption/ Water monitoring/ Water meter/	Y	4	Y	7

	Water usage monitoring				
b)	Waste water treatment	Y	1	Y	2
c)	Water recycle and reuse	Y	1	Y	5
d)	Minimize waste regeneration/ Water segregation/ Storage and disposal/ Recovery from waste	N	0	Y	3
e)	Water efficient landscaping	Y	4	N	0
f)	Innovative waste water technologies/ Strom water management/ Water recycling effluent discharge to foul server	Y	2	Y	2
6.	**MATERIALS**				
a)	Building reuse/ Reuse of façade/Reuse of structure	Y	6	N	0
b)	Conservation of efficient utilization of resources	Y	0	Y	0
c)	Utilization of fly ash in the building structure	N	0	Y	6
d)	Storage and collection of recyclables / Construction water management / Resource reuse/ Recycled content/ Construction waste management/ Recycled aggregates/ Recycled content of concrete/ Recycled content of steel/ Recycled content of reused product and materials	Y	2	Y	2
e)	Reduce volume Weight and time of construction by adopting an efficient technology	N	0	Y	4
f)	Use low energy materials in the interiors	Y	2	Y	4
g)	Sustainable procurement/ Recycling waste storage/ Sustainable construction/ Sustainable products/ Adaptability and deconstruction/ Sustainable products/Waste recycling facilities/ Waste management	Y	2	Y	1
h)	Local or regional materials	Y	2	N	0

7.	**TRANSPORTATION**				
a)	Alternative transportation/Public transport accessibility/Commuting mass transport/ Green transport/ Local transport/ Vehicular access	Y	8	N	0
b)	Alternative transportation/ Cyclist facilities/ Alternative transportation/ Travel plan/ Fuel efficiency transport	Y	4	N	0
c)	Pedestrian route/ Local transport	Y	1	N	0
d)	Proximity to amenities/ Neighborhood amenities/ amenities features	Y	5	N	0
8.	**INNOVATION**				
a)	Innovation in design	Y	5	Y	4
b)	Accredited professional	Y	1	N	0
c)	Optimization in structural design	N	0	N	0
9	Regional priority	Y	4	N	0
	Total		**110**		**104**

- The utmost important portion has been given by these rating tools (LEED and GRIHA) in ‘Energy Efficiency/ Use’ maximum score was assigned for the complete project life cycle in the assessment of green rating.
- The average score obtained by LEED and GRIHA was similar for ‘Indoor Environment Quality’ which plays a moderate role in rating tools.
- Higher prominence was given by GRIHA for ‘Recycle, Recharge, and Reuse of water’ compared to LEED in rating the building.
- GRIHA gave negligible scores for ‘Transportation’ while LEED considered it a moderate contribution factor.
- ‘Materials’ was equally considered as a high contribution factor by GRIHA and moderate contribution by LEED.
- ‘Health and Well Being’ was least considered by Indian tools.
- Minimal score was allotted for ‘Innovation’ by all these three tools.
- ‘Management/Sustainable Site’ was considered under the moderate category by GRIHA while a lesser score was obtained by LEED.

Energy efficiency and energy utilization have a major impact on the environment. In recent days rating tools have focused more on environmental compared to economic, social, and other geographical factors which lead to the partial sustainable assessment of building performance (Mattoni et al., 2018). It is often seen that many Indian assessment tools are replicated from other countries assessment tools with minor modifications that are barely sufficient to satisfy Indian conditions. It is mandatory to give equal importance to all three pillars like environment, economic, and social aspects of sustainability to complete the competitive sustainability assessment tool (Illankoon et al., 2017). Henceforth it is not favorable for a complete assessment of sustainability which is quite a complex phenomenon.

2.3.2 The green building construction scenario in India

As discussed earlier, construction industry is the main cause of environmental pollution and as we set our course for growth, it is critical that we keep an eye on the environmental damage that we do. It is critical to pause for a moment and make the necessary changes to benefit Mother Earth and future generations. The construction of green buildings is an emerged solution in this regard. It is a well-established fact that green buildings offer immense potential to reduce consumption and regenerate resources from waste and renewable sources and provide a win-win solution for users, owners, and the environment. During the construction and operation stages, the depletion of natural resources is comparatively less. Reducing the consumption of non–renewable sources of energy, efficient utilization of resources, and adopting the concept of reuse, recycling, and using renewable energy sources are the principal aims of green building design (Vyas et al., 2019b). This approach maximizes the use of renewable sources of energy, incorporates efficient waste and water management practices, and provides comfortable and hygienic indoor working conditions. To sum up, the following aspects of the building design are looked into in an integrated way in a green building design.

Buildings have been proven to have a high environmental effect and they are a significant source of energy consumption and GHG emissions. 39% of total energy consumption in the USA was from the building sector and within which consumption of electricity was found to be 70% (Koroneos and Kottas, 2007). In the UK, the energy consumption by the building sector was found to be 40 – 50% (Finnveden and Moberg, 2005). In Brazil, the construction industry accounts for more than 50% of national energy consumption during its operational phase (Melchert, 2007). India is the seventh-largest country in the world. The construction industry plays an essential role in the country's economy, which is reflected in the burgeoning real estate development taking place in India. In the light of the growing energy deficit, resource crunch, and increasing greenhouse gas emissions, it has become inevitable to shift to a greener construction industry. In India, various initiatives have been taken voluntarily for sustainable buildings.

IGBC started the "Green Buildings" movement in India in 2001, which was an initiative of the Confederation of Indian Industries (CII) along with the World Green Building Council and the U.S. Green Building Council (USGBC). The rated buildings are expected to consume 30 - 50% less energy as compared to a conventional buildings (Vyas and Jha, 2018). The LEED was an Indian green building rating system developed by the IGBC in October 2006 (Vyas and Jha, 2017). In 2015, the IGBC separately developed an IGBC Green New Building Rating System. The categories and weights adopted in this rating system were (Shan, and Hwang, 2018): sustainable architecture and design - 5%, site selection and planning - 14%, water conservation - 18%, energy efficiency - 28%, building materials, and resources - 16%, indoor environmental quality - 12% and innovation development - 7%. The IGBC assessment tool is developed for assessing new constructions, existing buildings, commercial interiors, cores and shells, homes, neighbourhood developments, schools, and retail showrooms. This tool provides ratings of buildings as Certified, Silver, Gold, Platinum, and Super Platinum. A simple checklist format is used in this tool to assess and rate the building's performance (IGBC rating, 2015).

GRIHA is a rating system to assess the performance of large consumers such as residential, commercial, and institutional buildings developed by "The Energy and Resources Institute" (TERI) (Vyas and Jha, 2017). GRIHA evaluates the environmental performance of a building holistically over its entire life cycle, thereby providing a definitive standard for what constitutes a "green building". The Bureau of Energy Efficiency (BEE), a government of India's statutory body had done benchmarking study with the collaboration of United States AID (USAID). The scheme is based on the actual performance of the buildings in terms of energy performance index (EPI, $kWh/m^2/Yr$), in which air-conditioned and non-AC buildings (offices, hotels, hospitals, retail malls, and IT parks) are rated on 1 - 5 scales targeting three climate zones (hot and dry, warm and humid, composite). Recently, the GRIHA version 2015 is applied to the Indian construction sector. The categories and weights adopted in this rating system are (Vyas and Jha, 2017): sustainable site planning - 8%, occupant comfort, and wellbeing - 12%, sustainable building material - 14%, energy - 20%, water - 17%, construction management - 9%, solid waste management - 6%, socio-economic strategies - 6%, and performance monitoring and validation - 8%. The GRIHA rates the buildings One Star if the score is from 25 - 40, Two Stars for scores 41 - 55, Three Stars for scores 56 - 70, Four Stars for scores 71 - 85, and Five Stars for scores above 86% (GRIHA rating, 2015).

Over the last several years, it is seen a dramatic increase in the construction of green buildings in India. India ranks third among the Top Ten Countries for LEED. Currently, India has 2190 LEED registered buildings and 398 LEED-certified buildings with 1.26 billion square feet built-up area and about 575 projects covering up to 21 million square meters are registered under GRIHA. Emerging economies such as India are engines of green growth, with development varying from two to six-fold over current green building levels.

2.3.3 Advantages of green buildings

New green buildings can have tremendous benefits, both tangible and intangible. The most tangible benefits are the reduction in water and energy consumption right from day one of occupancy. The energy savings could range from 20 - 30% and water savings could be around 30 - 50% (Vyas and Jha, 2018). The intangible benefits of new green buildings include enhanced air quality, excellent day lighting, health and well-being of the occupants, safety benefits, and conservation of scarce resources. A green building has lower resource consumption as compared to conventional buildings. A green building may cost more upfront but saves through lower operating costs over the life of the building. The green building approach applies a project life cycle cost analysis for determining the appropriate upfront expenditure. Some benefits, such as improving occupant health, comfort, productivity, reducing pollution, and landfill waste are not easily quantified. Sufficient fund allocation in the budget is essential to accommodate the cost for research and analysis of investment in green building attributes. Even with a tight budget, many green building measures can be incorporated with minimal or zero increased upfront costs and they can yield enormous savings.

The following is the average percentage reduction of various resources in a building and their respective reasons (Vyas and Jha, 2018):

• A reduction in power usage of 40 - 60% (depending on the range of measures used) as compared to typical structures. This is largely due to the fact that they rely on passive architectural interventions in building design. In the design of the building, they exclusively utilize high-efficiency materials and technology. All energy requirements are met by on-site energy generation using renewable energy. Solar thermal systems, for example, can assist create hot water and replacing traditional electrical geysers in buildings. Solar PV panels can assist in the generation of electricity, reducing the building's reliance on grid power.

• Water usage is reduced by 40 - 80 % (depending on the range of measures used) as compared to traditional buildings. Green buildings not only minimize their need for water usage by employing ultra low-flow fixtures, dual plumbing systems, waste-water recycling systems, and rain-water harvesting, but they also look at on-site supply alternatives to cater to both internal and exterior (landscape) water demands.

• Green buildings create less trash by utilizing on-site waste management techniques. They may also use waste to energy or resource (such as manure or compost) techniques on-site to reduce their reliance on municipal waste management facilities and landfills.

• Green buildings emit fewer pollutants both during development and when in use. Through best practices such as proper construction material storage, site barricading to avoid air and noise pollution during construction, suitable waste storage, and disposal during construction and operation, and so on. Green construction guarantees that the surrounding environment is not harmed.

• Green buildings provide adequate safety, health, and sanitation amenities for both construction workers and residents (while in use).

• Green buildings limit the use of chemicals with a high Ozone Depletion Potential (ODP) in their systems and finishes.

• Green buildings have a better image and are more marketable.

These may be accomplished at a low incremental cost, with an anticipated payback period of 3 - 5 years (excepting renewable energy for power generation).

2.4 BUILDING PROCESS AND LIFE CYCLE PERFORMANCE

According to Thomson et al., (2011), an assessment of building performance is required for "understanding the social, economic, and environmental impacts associated with how buildings and their support systems are designed, built, operated, maintained, and eventually disposed of". However, the lack of completely integrated evaluation technologies has led to the absence of a holistic assessment strategy throughout the life cycle of a building. The existing sustainable assessment tools and methodologies for sustainable building assessment were examined in the preceding section. Because the study is focused on assessing sustainable building performance at various development phases of building, the construction process and building performance will be examined in this chapter, making this study important, timely, and practical. Environmental, economic, and social consequences will be examined at various stages. The construction of any building can have various impacts on the environment and affect the environmental, social, and economic aspects of the community involved. So, we have to incorporate better sustainability parameters after understanding the life cycle of the building (Bhatt et al., 2012; Vyas and Jha, 2016).

2.4.1 Building stage divisions

The construction of any building can have various impacts on the environment and also can pose an effect on the environmental, social, and economic aspects of the community involved. So, we have to incorporate better sustainability parameters after understanding the life cycle of the building (Bhatt et al., 2012; Vyas and Jha, 2016). Four or five stages of the lifecycle of a building are more acceptable from a literature point of view. Four different divisions were made after inspecting the literature and questionnaire of the survey results:

1. Inception and design phase
2. Construction phase
3. Operation and maintenance phase
4. Demolition phase

2.4.1.1 Inception and design phase

This phase plays a significant role in enhancing building performance as it is at the start of a project. It is becoming more acknowledged as critical for the proper commissioning, operation, and maintenance of a building project. This is the phase at which the performance of sustainability with respect to environmental aspects may be determined by site location, materials, and technology. The conception and design stages are essential for the performance of building since the decisions taken here impact all other interdependent activities. This phase includes identifying the project's objectives, conducting a feasibility study of the project, preparing the preliminary and detailed design, and framing funding sources and cash flow statements (Chitkara, 1998).

Inception and design phase integrates all the sustainability considerations and helps design the framework for sustainable strategies to be adopted in the entire project (Hacking and Guthrie, 2008; Ramesh et al., 2010). This is the deciding stage of whether the project will efficiently achieve the set sustainability performance goals or project objectives. This impact can originate from the selection of site, materials, design, and considerations for local heritage conservation (Vyas and Jha, 2016). The economic impact at this stage includes investment planning, market forecasting, demand and supply analysis, etc. (Chauet al., 2015). This will have a compelling influence on the overall economy during the life cycle of the building. The land costs, project management consultancy service fees, and other miscellaneous charges are included in this stage (Hacking and Guthrie, 2008; Ramesh et al., 2010). The societal impact in this phase consists of the project's influence on the advancement of the community, nearness to facilities or services for the public, and conservation of traditions and culture (Vyas and Jha, 2016).

2.4.1.2 Construction phase

The construction stage includes the construction and installation of the building, procurement of materials, products, and services, and the final completion of the building (Chitkara, 1998). This stage analyses the energy, water, and resource consumption, waste generation, noise output, GHG emissions, and effects on the environment caused by transportation and building work. This phase directly affects the environment because of the excessive consumption of materials, energy, and water and improper treatment of waste and pollutants generated on-site during the construction of buildings (Hacking and Guthrie, 2008; Vyas and Jha, 2016). The economic considerations include the professional costs, construction costs, including labor, plant and materials costs, and other miscellaneous costs and charges involved (Chauet al., 2015). Most of the economic costs are incurred at this stage. The major social impact consideration in this stage includes the impact on the local community and the health and safety of the construction workers (Ramesh et al., 2010; Vyas and Jha, 2016).

2.4.1.3 Operation phase

The operation phase includes heating, cooling, lighting, ventilation, and water consumption. The consumption of energy and resources, the discharge of waste, and pollution were the main environmental setbacks that emerged in this phase (Hacking and Guthrie, 2008; Ramesh et al., 2010). The economic costs include the operation and maintenance costs, occupancy costs, and other miscellaneous costs such as utility consumption (Vyas and Jha, 2016). The major impacts of this phase on social aspects include the health and safety of the occupants, their satisfaction, stakeholder relations, security measures, and other risk management measures for fire safety (Chauet al., 2015; Ramesh et al., 2010).

2.4.1.4 Demolition phase

Demolition is the last phase in the life cycle of any building, which includes the collection and utilization of demolished buildings and their leftover materials. Nowadays, the dismantling process is increasing due to constant new developments occurring every year. Among all the other stages, this stage has the least favorable and major negative impacts on the environment regarding waste generation, noise pollution, and emissions (Chauet al., 2015). The economic aspect of this stage includes the demolition cost, compensation to stakeholders, and other minor costs like labor costs, administrative costs, and waste disposal costs (Ramesh et al., 2010). In the social dimension of this stage, the impact on the community and the health and safety of the community plays a significant role (Vyas and Jha, 2016).

As stated earlier, the development of construction projects may be classified into different phases, each playing an important part in the performance of building sustainability. Prior to this, many studies focused only on the construction phase of the project. But few of them have explored end-of-life possibilities in commercial building types (Guggemos and Horvath, 2005b), while others focused on the building construction phase (Bilec et al., 2010), while yet others focus on the building operation phase (Scheuer et al., 2003). However, few studies have taken into consideration all of the stages from a life cycle perspective. Because one phase may impact one or more of the other stages, the outcomes of a project's life cycle are highly interconnected (Wu et al., 2012).For a project to be sustainable, it must go through each step of its life cycle. It is possible to integrate all sustainability concerns from the beginning of the project and develop a sustainable strategy for it throughout the conception and design phases. Incorporating and increasing the sustainability of a project is the first step in the process. A project's long-term aims can be achieved during the building phase. Last but not least, the demolition phase covers reuse and recycling after a project’s operation period (Thomson et al., 2011; Wu et al., 2012). A construction project’s sustainability performance should, therefore, be evaluated in terms of the entire building’s life cycle.

Blengini and Carlo (2010) endorse this approach, by stating “an overall judgment on building sustainability should cover all life cycle phases”. Another factor is that various participants in the construction industry place different values on different items. The building performance is considered to be changing depending on the interest of different stakeholders in the development of the building (Cole and Larsson 1999). It is challenging to satisfy all stakeholders when considering an overall rating score to measure a building’s performance. In such a scenario, the performance ratings for each step are required. As a result, this study will evaluate the overall performance of the structure and the performance of various phases of the development of building project.

Table 2.4 summarizes the life cycle stages of a building project, their associated key activities, and the relevant sustainable impacts in all three pillars of sustainability. The environmental effect of each of these stages was evaluated, taking into account all of the key concerns associated with the influence on the environment. Building life cycles, as previously mentioned, may be divided into various areas since the building is considered to be a process rather than viewed as a product (Sev, 2011). The three aspects of sustainability are determined to have varied effects at different stages of development, according to the World Commission on Environment and Development (1998). According to Von Paumgartten (2003), including sustainable principles in the construction process may improve the performance of environmental and economic development. According to Kaatz et al., (2006), using environmental evaluations will improve its potential to influence design and construction practice by challenging the current norms and values of those responsible for building delivery. Thus, it is critical to analyze the influence of development on the whole construction process (Shen et al., 2002; Kaatz et al., 2006).

Table 2.4: Building stage division, activities and respective sustainable impacts in a construction project

Development Phases	Activities	Sustainability Pillars		
		Environmental	Economic	Social
Inception & design	a) Establish goals/aims/objectives b)Establish a project formulation proposal c)Conduct project appraisal d)Establish a project initiation proposal	Selection of site, biodiversity, natural habitat	Land cost, loan payment consultant fees	Cultural and heritage preservation, infrastructure and public facilities, and neighborhood development
Construction	a)Deploy resources b)Transporting resources to the location c)Complete building and installation tasks	Emissions into the atmosphere, discharge into water, landfill, land usage and pollution, resource consumption, local concerns, influence on the community and local traffic, hazards of environmental accidents, impacts on biodiversity	Construction costs (labour, plants and materials), professional fee	Opportunity for employment, on-site safety, and property integrity
Operation	a)Project Management, b)Operation and maintenance	Consumption of resources, energy consumption, water consumption, and pollutant emissions	Costs of operation, maintenance, payroll, and utility expenses	Health and comfort of occupants, stakeholder interactions, occupant satisfaction, and productivity
Demolition	a)Demolition & disposal	Waste disposal, landfill, operation of demolition	Waste disposal expenses, labour costs, staff deployment, and land-redevelopment-valued residues	Community satisfaction, safety and security

2.5 REVIEW ON VARIOUS INDICATORS ADOPTED IN THE MODEL

Various additional indicators are obtained from the literature surveys and are finally incorporated into the BPS. The indicators like topographical and climatic conditions, construction workers' health and safety, project management consultancy charges, operation and maintenance costs, security, and risk management measures are the additional indicators to the existing ones that are not actually included in the current assessment tools. The additions of these indicators will enhance the sustainable performance of a building in all three dimensions of sustainability.

Table 2.5: List of additional indicators adopted in the model

Sustainable Pillar	Indicator	Authors
Environmental	Topographical and climatic conditions	Zuo and Zhao, 2014; Kamali et al., 2018; Janjua et al., 2020.
	Domestic and solid waste segregation and management	Chau et al., 2015; Bundhoo, 2018
Economic	Project management consultancy (PMC)	Sarda and Dewalkar, 2016; Sharma, 2018.
	Operation and maintenance costs	Shi and Chew, 2012; Alexeew et al., 2015; Vyas and Jha, 2016; Darko et al., 2017; Kamali et al., 2018; Chen, 2010; Janjua et al., 2020.
Social	Risk management measures	Todd et al., 2001; Vyas and Jha, 2016; Vyas and Jha, 2016; Sharma, 2018.
	Security measures	Chau et al., 2015; Kumar and Selvavinayagam, 2019
	Construction workers' health and safety	Todd et al., 2001; Zuo and Zhao, 2014; Sharma, 2018.

i) Topographical and climatic conditions

The Indian climatic and weather conditions are very widespread across a very vast range of geographical areas and varied topographic scales, which makes it difficult in generalizing the assessment indicators for a building (Zuo and Zhao, 2014; Kamali et al., 2018). India has six major climatic subtypes. The country has an arid desert in the west. There are alpine tundra and glaciers on the northern side of the country. The southwest parts of the country and the islands have humid tropical rainforests. Buildings can be vulnerable to climatic change and the impact is felt by the construction sector (Janjua et al., 2020). The change in climatic conditions causes instability in the buildings with respect to location, design, building materials, and technology (Kamali et al., 2018). Therefore, the construction practices cannot be the same all around and it varies from one region to another because of the broad changes in climatic conditions across India. To tackle these impacts, we have to pinpoint the impacts of climate change on the construction industry. We also have to point out the gaps in the existing practices to tackle these issues. The most important factors affecting the environment arise from extreme weather - related issues like the workability of the concrete cast, the curing of the concrete, the hardening of the concrete, the choice of the site location, insurance claims, the standard building codes, delays in completing the projects, structural changes requiring extra cost cranes and scaffoldings (Zuo and Zhao, 2014). According to the site selected, the execution methodology can also change as soil conditions and the bearing capacity can be different from place to place. The builder should be aware of the weather conditions of the selected site: Short-term weather conditions and long-term climate conditions are important factors in deciding the suitable design and managing the construction project (Janjua et al., 2020; Kamali et al., 2018). Therefore, this becomes a crucial indicator to be considered in the sustainability performance assessment of a building to ensure both the environmental, social, and also economic sustainability well before the construction phase.

ii) Construction workers' health and safety

Construction sector is largely labor-intensive and is highly risk-prone due to the laborious processes involved (Todd et al., 2001). Construction accidents cause major economic and social issues when human life is lost or when a severe physical injury occurs at the site

(Zuo and Zhao, 2014). We have to enhance the working conditions to ensure the safety and well-being of the workers involved. The working hours should not be protracted too much and proper facilities for health check-ups and follow-up should be available for the construction workers. Emergencies and casualties should be appropriately handled. Preventive healthcare services and proper training given to the workers can help to avoid most of the adverse situations in the construction industry. Moreover, other factors like health, hygiene, cleanliness, basic facilities, and safety with respect to the construction worker's dwelling place make up a major aspect in protecting the social well-being of the workers. This aspect adds up to the social sustainable performance of any building during its construction stage (Sharma, 2018).

iii) Project management consultancy (PMC)

The construction industry generally comprises various types including the residential, commercial, industrial, and corporate segments. To handle such unique projects, an expert with sound knowledge is needed to facilitate a win-win situation in meeting all the requirements of the client. A systematic approach toward project management consultancy includes the inclusion and usage of higher management tools like reporting dashboards, progress reviewing, conducting brainstorming conferences, regular quality audits, and quality diligence. Incorporation of PMC in the project life cycle proves more effective and efficient when it is applied from the very beginning of the project until its closeout in a project life cycle (Sarda and Dewalkar, 2016; Sharma, 2018). Good awareness is needed about the various constraints in the project period like the time required, cost of the project, quality maintained, the scope of the work, and the risks involved. A good idea about the resources and the various processes involved throughout the life cycle in a deeper sense is the most elemental part of any PMC. The inclusion of PMC and its respective charges in the building life cycle during the planning and construction proves to be an effective sustainability measure in terms of the economic life of a building in the long run (Sharma, 2018).

iv) Operation and maintenance costs

The acquisition, maintenance, and disposal of a building or a building system depend upon numerous costs involved (Kamali et al., 2018). There are operating costs and maintenance costs involved in addition to the repair and miscellaneous costs like electricity generation and transmission costs. Sometimes equipment operation costs are generally more difficult to calculate than other building expenses. Even for the buildings with the same life and similar type, there is much variation in the schedules of operation and maintenance and their respective costs involved. Thereby it becomes necessary to implement proper judgment when the costs are estimated. The overall assessment of the economic aspects of the building construction becomes a factor in the economic sustainability aspect during the operation stage of a building and thereby helps to plan and reduce the cost associated with the energy consumption (Janjua et al., 2020). The use of renewable energy to produce electricity will add more green, and sustainability and reduce the cost of operating the building (Shi and Chew, 2012). Many researchers suggested that precast and prefabrication in building components will have a remarkable impact on cost and sustainability (Chen, 2010; Vyas and Jha, 2016; Darko et al., 2017). The initial cost of a green building may be slightly more but it saves on the operational cost with respect to the age of the building (Alexeew et al., 2015; Darko et al., 2017).

v) Risk management measures

Risk is nothing but exposure to the consequences of uncertainty. Risk is a multi-angle concept. With respect to the construction field, risk could be any definite occurrence of an event or a combination of events, which may arise at any point in a whole project life cycle that could be detrimental to the project because of its unpredictable nature (Todd et al., 2001). The association of uncertainty with any risk factor could accord the outcomes that are either better or worse than expected. The risk exposure can be managed by proper planning, monitoring, and controlling the various factors causing the risks involved. For this purpose, the risk - causing factors should be identified and the extent of risk calculated. This will help to provide the necessary measures to control the risk and manage any residual risks involved (Sharma, 2018). The risk factors appearing in the construction stage can be technological, political, environmental, social, or financial. The procurement of material can create both internal and external types of risk. Improper planning, design, scheduling, improper site selection, and time management issues can increase the risk (Vyas and Jha, 2016). These risks can cause different kinds of losses like damage to property, loss of time, loss of production, loss of money, loss of contracts, or accidents on construction sites. These factors can seriously affect the reputation of the companies involved and will certainly affect their future business opportunities. During the operation stage, the causes of risks may either be natural or anthropogenic; the effects will cause more significant damage to human life, housing, community infrastructure, environment, livelihood, health, and psychosocial behavior of the affected people. Therefore, well - structured risk mitigation and management plan to accommodate any favorable or unfavorable situations that may or may not arise during any stage in a building life cycle is a necessary and significant component in any construction practice (Vyas and Jha, 2016). The inclusion of this factor in the assessment indicators for sustainable building concepts will affirm a stable and positive outcome in terms of environmental, economic, and social wellbeing.

vi) Security measures

Most of the buildings made in the current period are designed in safer and environment-friendly conditions. The protection of Health, Safety, and Welfare of the workers (HSW) go beyond disease prevention and nuisance control; the entire ecological impact and the creation of healthy living space are involved in the whole process (Chau et al., 2015; Kumar and Selvavinayagam, 2019). A building with proper security means that it includes provisions for security measures like a compound wall, access control, and an intrusion detection system on the perimeters. Facilities should also be available for the protection of information and data and personnel identification. Video cameras and CCTV surveillance systems help to increase the safety of the compound.

vii) Domestic and solid waste segregation and management

The erroneous administering of solid waste can impact the public health of entire communities and cities because it pollutes potable water, land, and air. Solid waste can increase pollution and accelerate the depletion of forests and mines. The proper collection, segregation, and waste management start from within the basic unit of a building (Chau et al., 2015). The proper management and segregation of the waste generated within a building from the day-to-day activities can help to take appropriate measures for further recycling and reusing of the non - decomposable materials that can cause irreversible damage to the environment (Bundhoo, 2018). For a long time, solid waste management was considered the responsibility of the companies involved or the municipality or government that has jurisdiction in the area. But every household should be aware of the measures taken for the reduction and proper management of the solid waste generated. This helps to make a building perform more sustainably in terms of both environmental and economic aspects throughout its life cycle.

2.6 SUMMARY

The notion of sustainability and the TBL of sustainability were explored. Following that, a review of the TBL for assessment of the building was carried out. The assessment approaches of three legs of sustainability, namely, environmental, economic, and social aspects for evaluating the building performance are examined. LCA techniques are addressed in environmental assessment, followed by their application in the building sector. This chapter discussed SIA and other techniques for social evaluation. The construction industry is critical to long - term growth. Meanwhile, sustainable building evaluation methods and techniques are critical to globally regulating and promoting sustainable building. Several sustainable assessment methods and techniques also contrasted and analyzed the application of the well - known and reputed worldwide tool, LEED, and the tools extensively used in India, namely, LEED - India and GRIHA. With significant regional features such as climate, economic condition, values, and other concerns, it is doubtful that sustainable assessment techniques would be used directly in different locations. Furthermore, existing evaluation techniques seldom take into account the pillars of sustainability at all stages of the building life cycle. As a result, there is an urgent need to create a tool that takes into account the three pillars of the building life cycle and is tailored to India's specific needs. Previous research on the creation of models for assessing the environmental performance of building is also highlighted. According to the description above, analyzing building sustainability performance at various phases of the life cycle is essential and feasible. Further, the additional indicators in each sustainability pillar adopted in the model have been discussed. In the following chapter, the research design and methodology are discussed to develop the model and approach to validate the model.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

In the Indian context, existing assessment tools provide major importance to environmental impact rather than economic and social impacts. This imposes an urge to develop a building performance assessment model for the country. The research design and methodology adopted to develop the model and validate the same are discussed in this chapter. In this study, both qualitative and quantitative methods are used. Data is collected using surveys and semi-structured interviews, and the model is developed and validated through case studies.

3.2 RESEARCH METHODOLOGY

Based on the detailed literature survey, it was observed that the shortcomings in the current building assessment rating system created a demand for a new assessment model in India. Therefore, developing a model is the most important aim of this study. In order to do this, a suitable research methodology is to be adopted to achieve the research objectives. According to (Williams, 2007), qualitative, quantitative, and mixed methods are commonly used approaches in research studies. The qualitative method is used when the research requires textural data and the quantitative method is used when the research requires numerical data. Mixed method is used when the research requires both textural and numerical data.

3.2.1 Qualitative methods

Qualitative research involves obtaining and analyzing information about a phenomenon without considering numbers (Patton, 1990; Thomas, 2003). The qualitative analysis is always predicated on capturing data from a literature study, and data collecting methods include participant opinion, extensive interviews, comprehensive descriptions, and case studies. This technique enables academics to investigate certain topics in-depth and in detail. These methods focus on inquiry, discovery, and inductive logic of a particular problem. These also serve as a rational approach, as there is no such accepted, valid, and reliable quantitative measurement that exists for certain outcomes. Through in-depth case elaboration, qualitative data may flesh out quantitative results and bring them to life. Table 3.1 shows the advantages and limitations of the qualitative method.

Table 3.1: Summary of advantages and limitations of qualitative method

Types	Contents	Advantages	Limitations
Case study	A case study generally includes a description of an entity and its activities, as well as reasons for why the entity acts the way it does.	It can indicate how various variables interacted to generate the distinct personality of the thing under investigation.	It is challenging to apply generalizations, ideas, or circumstances from one to another without significant risk of mistakes.
Ethnography	Cultural anthropologists' primary approach is ethnography, which is a type of case study.	It can disclose traits shared by members of group–characteristics that distinguish the group's culture–helping research consumers comprehend how and why one group differs from another.	Conclusions obtained from ethnographic studies of one group may only be transferred to other groups with great caution due to the unique variables that may influence the pattern of life in each location.
Experience narrative	It refers to an occurrence as reported by someone who was there during the episode, either as an active participant or as a spectator.	It allows readers to engage vicariously in the thoughts and feelings of others as they relate to situations that they would never personally experience in their own life.	Experience narratives are ineffective tools for explaining how traits are dispersed across a population.

According to table 3.1, the advantages of utilizing qualitative approaches allow for more flexible involvement and expose a multiplicity of ways. The critiques of qualitative techniques focus on the errors and problems associated with the implementation of the results.

3.2.2 Quantitative methods

The quantitative approach involves the use of standardized assessments so that the various perspectives and experiences of people may fit into a limited number of predetermined answer categories to which numbers are assigned (Patton, 1990). As a result, quantitative techniques are methodical, standardized, and easily presented in a condensed space using numbers and statistics they are also brief, sparse, and pooled conveniently for analysis (Thomas, 2003). The project always begins with a brief explanation of the topic and includes methods like running tests, conducting surveys, and gathering data using predetermined tools (Patton, 1990; Creswell and Creswell, 2009; Thomas, 2003).

The quantitative measurement and analysis based on numerical measurement of specific properties of events are easily replicable by other researchers (King, 1994). There are four types of quantitative studies: surveys, experiments, correlation research, and progressive studies. Their advantages and limitations are explained in Table 3.2. Surveys, for example, are useful for exposing the present status of a predetermined variable inside a certain entity. Despite this, they fail to demonstrate how the determined variable fits into the overall pattern. Statistical data for computation and more accurate information is obtained by correlation analysis, but the quality of the data on which it is based is determined by the data on which it is based.

Table 3.2: Summary of advantages and limitations of quantitative methods

Types	Contents	Advantages	Limitations
Survey	A technique for gathering quantitative data on things in a population.	Useful for determining the current state of a target variable within a certain object.	Fails to show the unique way that the target variable fits into the pattern.
Experiment	It is a strategy for assisting individuals in choosing between hypotheses or solutions.	One of experiment's benefits is its ability to establish cause-and-effect correlations. It is useful to put ideas and assumptions about how physical processes function under certain conditions to the test.	The experiment's shortcomings include a lack of generalizability and external validity.
Correlation study	It is a scientific investigation in which a researcher explores the relationships between variables.	Calculation methodologies are provided, as well as more accurate information.	It is only as effective as the data it is built on.

According to the discussion in sections 3.2.1 and 3.2.2, qualitative and quantitative research methodologies each have their own advantages and limitations. The mixed techniques are explained in the next part in order to embrace their benefits while avoiding their disadvantages.

3.2.3 Mixed method strategies

Most research does not fall neatly into one of two categories, qualitative or quantitative (King, 1994). The finest frequently incorporates aspects of both. Some data collected during a study project may be statistically analyzed, while other equally essential information is ignored. The research technique is acceptable for answering certain sorts of questions but not for answering others (Thomas, 2003). Using a blend of qualitative and quantitative approaches usually yields the best solution.

Triangulation is a method that was created in 1979 as a means of achieving convergence between qualitative and quantitative methodologies (Jick, 1979; Creswell and Creswell, 2009). Triangulation efficacy is predicated on the idea that the defects of one approach will be compensated by the counter-balancing qualities of another. This is presumptively based on the assumption that the various and independent measures do not have the same strengths and limits. Over 60 projects were included in the US AID evaluation special study series to demonstrate that are raised include how researchers may incorporate qualitative and quantitative data, what methodology they should employ, whether they should conduct direct fieldwork, utilize secondary data, conduct interviews, or mix all of these approaches. Early in the 1990s, the mixing concept expanded to include the real integration or link between quantitative and qualitative data, rather than merely convergence (Patton, 1990). Furthermore, qualitative and quantitative data may be combined into a single massive database, or the findings can be utilized in tandem to support one another (Creswell and Poth, 2016).

The advantages of both the methods, qualitative and quantitative, and these are combined in the mixed method because of its broader applicability (Table 3.3). Here, the qualitative method basically deals with information obtained from interviews, observation, documents, and audio - visual data whereas the quantitative approach deals mainly with information and data obtained from performance, attitude, observation, and census information. When these two methods are combined, dealing with multiple forms of information and data is possible and this is called mixed methodology. Hence, the analysis of both statistical and textual data can be carried out when the mixed method is adopted.

Table 3.3: Characteristics of quantitative, qualitative and mixed methods

Quantitative method ⟶ Mixed method ⟵ Qualitative method

Quantitative method	Mixed method	Qualitative method
• Pre-determined • Instrument based questions • Performance data, attitude data, observational data and census data • Statistical analysis • Statistical interpretation	• Both pre-determined and emerging methods • Both open-and closed-ended questions • Multiple forms of data drawing on all possibilities • Statistical and text analysis • Interpretation across database	• Emerging methods • Open-ended questions • Interview data, observation data, document data, and audio-visual data. • Text and image analysis • Themes, patterns interpretation

3.3 DATA COLLECTION PROCESSES

When individuals talk about research techniques, they frequently refer to the processes and equipment used to collect data. Content analyses, observations, interviews, surveys, inventories, and case studies are just a few of the essential procedures and tools (Thomas, 2003). Each of these techniques has its own set of advantages and disadvantages.

Although content analysis is the most effective method for identifying various research topics, it is time-intensive. Both direct and mediated observation enables researchers to see and/or listen to occurrences and create a record of them. Researchers can obtain a large quantity of data with questionnaires in a short amount of time, but response rates are poor, which is comparable to inventories, which has frequently troubled the researchers. As opposed to questionnaire surveys, interviews provide researchers more freedom and personal control, although their presence may skew replies (Thomas, 2003). Table 3.4 summarizes a comprehensive review of the benefits and drawbacks of various data-collection techniques.

Table 3.4: Advantages and limitations of data-collection process

Process	Content	Advantages	Limitations
Content analysis	The act of searching through one or more communications to find answers to queries that the investigator brings to the search is known as content analysis.	It is appropriate for obtaining information on the contents of messages. It is the only approach suitable for answering a wide range of research topics.	In proportion to the quantity of information gathered, content analysis is time-consuming and difficult. The accuracy and comprehensiveness of an analysis's conclusions are heavily reliant on researchers.
Observations	Observations include observing and/or listening to events and then documenting what happens. It might be direct or indirect.	It gives information from spontaneous and unexpected events for direct observation with no additional equipment necessary. The visual and audio records can aid researchers in reviewing crucial features of mediated observation.	It is sometimes impossible for the observer to make a quick, precise record of direct observation. In the case of mediated observation, the reliability of the observer's report is still debatable because it is heavily reliant on people's subjective inferences.
Questionnaire	Questionnaires are a series of questions that survey participants are asked to answer. It is usually used to gather information and views.	They allow a researcher to collect a great amount of data in a short period of time and can generate a wide range of information from respondents. Data may be obtained from people in remote locations without the researcher being present.	The low response rate of questionnaire surveys is a serious drawback. Participants can readily neglect the form if the researcher is not there to oversee them.
Interview	In most cases, an interview	Interviews provide the researcher with	Provides indirect information that has

	consists of a researcher asking someone to answer questions orally. It has traditionally been done in person, although it may also be done over the phone or the internet.	more freedom and personal control than surveys offer. Interviews are more efficient than direct observation for gathering information about people's expertise, personal histories, and attitudes.	been sifted through the perspectives of respondents. Provides information at a specific location rather than in the natural field environment. The presence of a researcher may sway replies. Not everyone is equally eloquent and insightful.

3.4 RESEARCH METHODS USED IN CONSTRUCTION INDUSTRY

In recent decades, the research methodologies have been widely utilized in the construction sector to assist researchers in conducting their studies and determining the worth of new items. They conducted a questionnaire survey across Ireland to ascertain the extent to which information technology systems were used in a life cycle cost analysis. They claim that the use of a questionnaire as a data-gathering methodology was motivated by the kind of population, the majority of whom could not find time for an interview, as well as the growing expense of alternative data collection methods (Matipa et al., 2009).

Fiedler and Deegan (2007) documented an assessment of environmental partnerships in the Australian building and construction sector through a series of extensive interviews with persons from construction firms as well as environmental organizations. Perry (1998) mentioned prior theory as being utilized to give a focus on the data collecting phase in semi-structured interviews. Using in-depth interviews, he found various reasons to push the partnership of certain environmental groups and construction businesses on selected projects.

In addition to utilizing a single research technique, several studies used other approaches for data gathering. Tam et al. (2012) used a survey form and semi-structured interviews to explore the variables impacting the application of green building in the Hong Kong construction sector. The study begins with a pilot questionnaire survey distributed to ten practitioners, followed by physical interviews to collect reviews and opinions on the questionnaires' clarity and appropriateness. This technique has the advantage of allowing for better integration between questionnaires and interviews. Varnas et al., (2009) have taken a similar strategy. They utilized a questionnaire survey in conjunction with interviews to investigate the existing practices, issues, and possibilities in green building contract procurement in Sweden. The study's questionnaire aims to offer an overview of the usage of environmental priorities in the procurement of construction projects, while interviews were conducted to gain a deeper understanding of the motives for incorporating these environmental considerations. In other words, the surveys give a foundation, but the interviews, on the other hand, give a more in-depth discussion.

Interviews were utilized as a support to the questionnaire survey in these research projects. However, interviews can also be employed in conjunction with the questionnaire survey in other research. Jensen and Johannesson (2013) performed a study to investigate the application of Building Information Modeling (BIM) across Europe's Nordic nations. The information was obtained in two countries: Iceland and Denmark. The questionnaire survey was carried out in Iceland, while the interviews were carried out in Denmark. Following that, both studies were tackled at the same time, with an emphasis on how BIM implementation lessons from one country might be used in another nation.

Arif et al. (2012) used case studies and semi-structured interviews to examine the adoption of waste management strategies in the Indian construction business. They stated that case studies may be seen as an in-depth investigation of a research problem because empirical inquiry that analyses contemporary occurrences within their real - life setting is more successful when the boundaries between phenomenon and context are clear. The semi-structured interview was referred to as the qualitative research interview by King

(1994), who stated that the qualitative interview is well appropriate when a study focuses on the significance of certain occurrences to the participants.

Some researchers have utilized more than two approaches for data gathering in addition to two method combinations. Häkkinen and Belloni (2011) addressed the real challenges and drivers for sustainable buildings through document examination, interviews, and case studies. Their study began with a critical evaluation of the current barriers and drivers and a web - based investigation. After that, interviews were conducted to determine what needs to be changed, and case studies were conducted to examine the possibilities for enhancing sustainable construction processes and the benefits of sustainable buildings. These three approaches collaborated to conduct this study. Lam et al., (2011) proposed a green specification framework for modeling current green specification systems in Hong Kong. In addition, the project began with a literature review in support of the core elements of the framework and then collected data for the framework using a questionnaire survey and interviews. Such research frequently uses a literature review as a basis or inspiration, followed by a questionnaire survey, interview, or case study to test their hypotheses, collect data, and draw conclusions. It is critical to evaluate the entire range of data collecting possibilities while deciding on the best sort of research approach for this study.

Table 3.5 highlights some of the approaches utilized in contemporary construction industry research. The one or more approaches chosen in the research works are all dependent on their own study aims and objectives. According to the table, some research studies use only one technique, such as a questionnaire survey or interviews, while others use two or three. Combining the techniques for doing the study can assist to embrace the positive aspects while avoiding the negative aspects.

Table 3.5: Research methods used in construction industry

Methods	Research studies	References
Questionnaire survey	Determines the extent to which IT systems were employed in Ireland as part of a whole life cycle cost study.	Matipa et al., 2009
Interviews	An evaluation of environmental partnerships in the Australian building and construction sector was documented.	Fiedler and Deegan (2007)
Interviews	Investigated the viability of building collaboration in Mainland China.	Hong et al., (2012)
Questionnaire survey, Interview	The current practice, challenges, and prospects of green procurement of construction contracts in Sweden were investigated.	Varnas et al., (2009)
Questionnaire survey, Interview	The variables influencing the deployment of green buildings in the Hong Kong construction sector were investigated.	Tam et al., (2012)
Questionnaire survey, Interview	Investigated the deployment of building information modeling (BIM) in Europe's Nordic nations.	Jensen and Johannesson (2013)
Interviews, Case study	The adoption of waste management methods in the Indian construction sector was evaluated.	Arif et al., (2012)
Document review, Interviews, Case study	The actual challenges and motivations for sustainable construction were addressed.	Häkkinen and Belloni (2011)
Literature review, Questionnaire survey, Interviews	Modeled by proven green specification systems in Hong Kong, they proposed a green specification framework.	Lam et al., (2011)

3.5 RESEARCH DESIGN

It is critical to evaluate the entire range of data collecting possibilities while deciding on the best sort of research approach for this study. Advantages and limitations of qualitative and quantitative methods as discussed in Tables 3.1 and 3.2, error causes, probable bias, strengths of triangulation, etc. should all be considered while adopting the research design.

Fellows and Liu (2008) said that some popular construction techniques include questionnaires, interviews, and case studies. Each of these approaches has advantages and disadvantages. In modern research efforts, these approaches can be used alone or in conjunction to aid in the execution of a study (Table 3.5). Figure 3.1 demonstrates that the questionnaire is broad but not deep enough, whereas the case study is deep but gives limited findings. The interview is sandwiched between them. Choosing any of these may result in a wide but shallow study on one end of the scale or narrow but thorough research on the other.

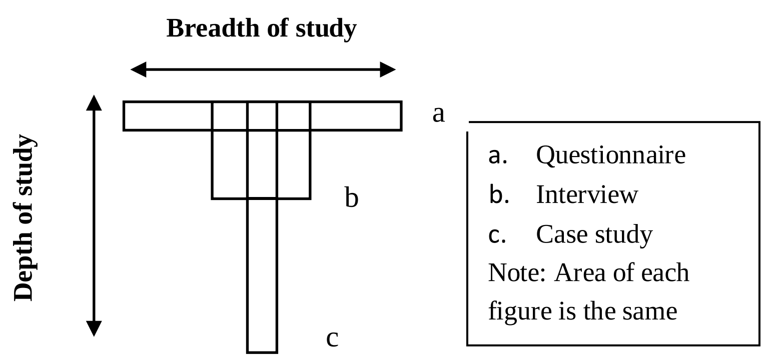

Figure 3.1: Breadth v/s depth in the research (Source: Fellows and Liu, 2008)

The aim of the study is to develop a model to assess the building's performance throughout its life cycle. The three pillars of sustainability are considered in the study. Initially, the gaps in present assessment tools are identified following which research aim and objective are developed. Literature review is conducted to have a better understanding and discussion on sustainable development and the concept of the triple bottom line approach. Assessment approaches related to the TBL concept are also discussed. Next, tools and models to assess the performance of sustainable buildings are reviewed to give a better understanding of the green building assessment method. The building process and performance of a building throughout its life cycle are also reviewed.

From the literature review, gaps have been identified in developing a sustainable building assessment model at different stages in the life cycle of building, particularly in India.

Questionnaire is used to collect the primary data regarding green building assessment in India and also to obtain data to develop a model from a big sample. Information such as the current situation of green buildings in India and important indicators for developing the model is collected from the questionnaires. This is used as the basis for further data analysis. Questionnaires are basically used for broader data collection. Interview is required in the research to have a depth discussion of some issues in the questionnaire survey (Thomas, 2003; Fellows and Liu, 2008; Creswell and Creswell, 2009). This also helps in obtaining a detailed explanation regarding the information from the participants which is difficult in the questionnaire survey.

A semi-structured interview was adopted to obtain detailed information from the participants. These are the two methods adopted in the present research for data collection. These two methods will help in obtaining data being both broad and in-depth as shown in Figure 3.2. Questionnaire survey is used in the present research because this research requires broad data in order to get the general opinion of the participants regarding green buildings along with assessment in India. Even the indicators considered also need broad data so that they are adequate and bias is avoided.

When these kinds of research methods are considered, they are used in different forms. Questionnaire survey consists of questions that appear in two forms such as open or close. Interviews are basically structured, semi-structured and unstructured. These forms are generally classified into one-way and two-way communication (Fellows and Liu, 2008). One-way communication consists of postal questionnaires, structured interviews, diaries, and interpretations by researchers. Two-way communication methods include feedback and obtaining further data through semi-structured interviews. These are also considered linear (one-way communication) and non-linear (two-way communication) methods. Linear method concentrates on data transfer and the non-linear method focus on transferring the meaning. Both linear and non-linear method is adopted for data collection along with questionnaire survey with closed questions and semi-structured interviews.

Closed questions help obtain broad data in a short period of time and hence it is adopted in the research. These can be more precise and targeted. Semi-structured interview is also used for in-depth discussion.

Assessment indicators selected for the model depend on the results from the questionnaire survey and semi-structured interviews along with the literature survey conducted in Chapter 2. The assessment model is developed based on these assessment indicators and later validated using case studies. Observations of the participants, interviews, and documents are required for data collection regarding the case studies.

To sum up, mixed qualitative and quantitative method is used for the data collection process in the research. Following this, a conceptual framework is generated and then begins the data collection process, development of the model, and validation with the case studies. Questionnaire surveys and interviews are used for the data collection process resulting in data being both broad and depth enough. This helps in overcoming the shortcoming of either of the methods and incorporates the advantages of both methods. Figure 3.2 shows the research flowchart.

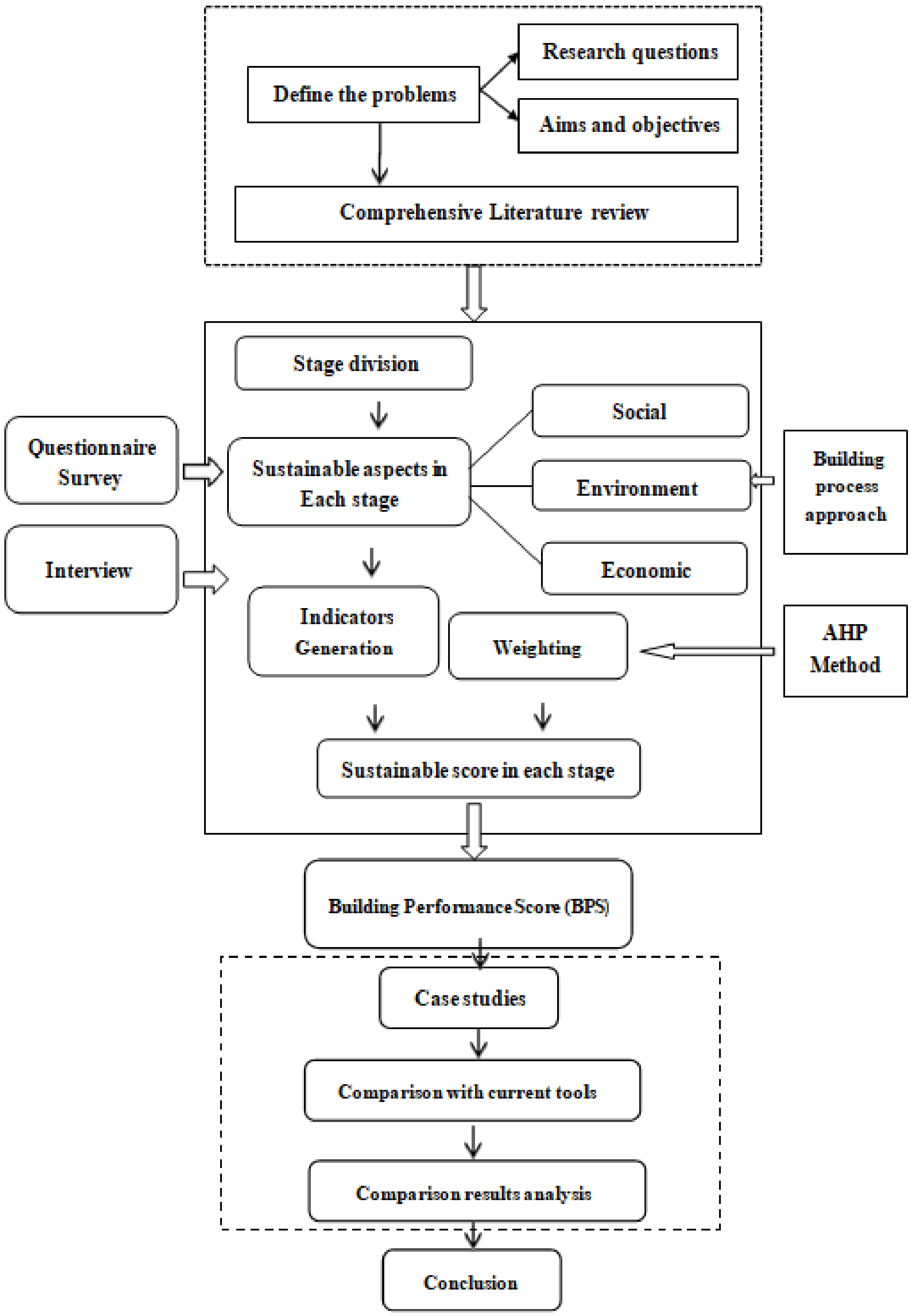

Figure 3.2: Research flowchart

3.6 SUMMARY

Various research methodologies have been examined in this chapter. In this study, mixed techniques (triangulation) are employed after analyzing their benefits and limits, as well as taking the peculiarities of this research into account. For data collecting for model development, questionnaire surveys and interviews were used. Survey provided the data required for model development, while interviews provided more in-depth and unanswered topics raised in the questionnaire survey.

Following this, the next chapter explains the data gathering technique used in this research work. Further information regarding data collection from survey and interview results with its analysis and discussion is elaborated in the next chapter. Following data analysis, a model will be developed. Case studies will be utilized to validate the model.

CHAPTER 4

DATA COLLECTION, ANALYSIS, AND DISCUSSION

4.1 INTRODUCTION

The research techniques were mentioned in the previous chapter. This chapter describes the data collecting method as well as the outcomes of data analysis. The findings were examined in light of the previous chapter's literature review. The goal of this chapter is to provide the results of the data analysis and draw conclusions from them, which will be used to construct the decision model for building evaluation later. This chapter contains an assessment of the results of an industry questionnaire survey and semi-structured interviews. The primary structure is converting quantitative and qualitative data into usable knowledge. The present state of green construction and sustainable evaluation methods in India is examined. Following that, the project development phase division and related sustainable implications in various phases of construction are examined.

4.2 DATA COLLECTION PROCESS

Based on existing research and studies, a model that takes into account the TBL of sustainability in the building phases is required for construction in India. To create such a performance assessment model, the assessment indicators must first be identified. Furthermore, local data on the present state of green construction in India offered useful information for this study. As a result, the industry survey, which combined a questionnaire survey and a semi-structured interview, was intended to collect primary data from India's construction sector.

4.2.1 Questionnaire survey

The questionnaire survey was performed to gather input from experts in the construction industry regarding the evaluation indicators as well as the present state of green building and assessment in India and to collect data for the model development. A professional in the construction business is often characterized as someone who has expertise or competence in a certain job or activity. As a result, the experts considered for this study either work in the construction business or have a career that is closely related to it. They had several years of work experience. People with expertise dealing with green or sustainable building, on the other hand, will be given preference. This approach focuses on assessing the performance of building at various development phases of building utilizing the three pillars. As a result, the survey required to start with the building stages. Furthermore, getting the assessment indicators is the primary goal of the survey. A questionnaire survey was carried out in order to collect data.

Both pilot and main surveys were conducted in the online mode to gather relevant data for analysis. According to (Villoria Saez et al., 2012), there are three key benefits of completing a questionnaire online.

- Efficiency: The most efficient method of interacting with stakeholders engaged in the construction process is via electronic mail.
- Privacy: An online survey ensures the privacy of the responses at all times, making it more confidential.
- Questionnaire length: An online survey allows respondents more freedom to explore and revise their thoughts.

i) Survey sample

The purpose of sampling is to provide a practical method for gathering and analyzing data for the study while ensuring that the sample gives a good representation of the population (Fellows and Liu, 2008). A survey sample should be selected based on the requirements in order to obtain the necessary information, while selecting sample size, researchers sometimes overlook sampling errors. They also frequently fail to address potential responder biases.

The preliminary function of sampling methods is to define the population, which is essential since the population determines the collection of entities from which the study sample is selected (Eisenhardt, 1989). In the sampling frame, there are three primary types of sampling methods: random sampling, judgmental sampling, and non-random sampling (Fellows and Liu, 2008). Each member of the population is given an equal chance in random sampling. Judgmental sampling refers to the application of judgment to select which objects from the population should be included in the sample. Non - random samples, such as systematic, stratified, and cluster sampling, are useful when a population is divided into categories.

In the case of a vast population, judgemental sampling may be utilized. Judgments aid in determining which members of the population should comprise the sample. The sample for this study was made up of experienced construction industry specialists or individuals directly linked with the sector, such as a government official in charge of green building evaluation. Such a sampling approach, however, may create bias. This study is about building performance, which is heavily influenced by stakeholders' subjective opinions, particularly about social impacts. Professionals were chosen as the primary group because they had green building experience and knowledge, as well as the professional ability to give solid recommendations. Furthermore, they featured a variety of viewpoints and points of view in order to give their perspectives on India's sustainable building evaluation.

This study was intended to be carried out primarily in the state of Karnataka, India. This was chosen as the primary target because of its highly developed economy in India today and also served as a model for green construction development. In Karnataka, professionals there have greater opportunities to interact with green building initiatives and appraise green buildings. Their knowledge and expertise would have a beneficial impact on the survey findings. Green building consultants, service engineers, architects, constructors, structural engineers, cost engineers, and academicians were among those who took part. Those experts come from a variety of construction businesses and educational institutions. Some originated from commercial enterprises, while others came from government agencies. Their diverse origins also affected their perspectives on green architecture.

ii) Sample size

The essential qualities of sample size are consistency, efficiency, and sufficiency (Fellows & Liu, 2008). A consistent estimator variance reduces as the sample size rises. Large sample size is required to provide an impartial outcome. The construction industry has a reputation for having a low response rate to questionnaire surveys.The following equation is used to formulate the sample size of the survey (Kasim et al., 2018):-

$$SS = \frac{Z^2 * (p) * (1-p)}{C^2} \qquad \text{……………..} \quad \text{Eq. 4.1}$$

Where, SS = sample size

z = standardized variable

p = percentage picking a choice expressed as a decimal

C = confidence interval expressed as a decimal

The sample size is calculated using this formula depending on the required accuracy and the level of confidence. In this study, a 95% confidence level with a significance of, α = 0.05; z = 1.96, and a confidence interval, c of ± 10% is considered (Kasim et al., 2018). The minimum sample size of participants required is 95 was obtained from Equation 4.1.

iii) Questionnaire development

The questionnaire was created to better understand the existing sustainable building evaluation in India and gathers more data for model improvement. Personal information, general questions, and model development were the three components of the questionnaire. The first section is personal information, which includes questions about name, employment experience, and qualifications. This is done to gather background information about participants. Part two includes general questions concerning the present state of green construction and green building evaluation in India. The present state of green building evaluation is described in the previous literature study. This section aims to acquire a better understanding of the present situation in India and to offer inspiration for the model development. The final part is dedicated to model development and contains questions regarding building life cycle stage division, critical concerns in measuring environmental, economic, and social performance, and so on (see Appendix I). It has to be seen whether it is appropriate for the Indian context. Because the sustainable building evaluation has a strong regional character, integrating the opinions of local experts in the phase division becomes critical. Other critical concerns that are addressed in this survey included assessment indicators. The expert perspectives on evaluation indicators aided in making the model more adaptive to the Indian situation.

iv) Pilot Study

Following the development of the questionnaire, a pilot study was required prior to the main survey. The pilot survey was designed to ascertain if these questions were understandable and how long it took respondents to complete the survey, whether they responded correctly, and so on. It aided in the identification of some issues and the polishing of the final surveys. For this pilot study, it has been identified that 32 respondents were 4 respondents were not considered because of their incomplete responses. Henceforth, the remaining 28 survey respondents were considered for further analysis. In general, the pilot survey yielded positive findings. This questionnaire took them about 15 to 20 minutes to complete. However, certain issues were discovered in this survey. Some of the questions were excessively broad or had contradictory interpretations. They were updated when the participants pointed this out. The pilot survey input, such as the logical relationship of each question, was included in the final survey.

v) Main survey

The primary questionnaire survey was conducted online, and 123 people responded positively. These experts were selected from various parts, primarily from the State of

Karnataka, India. The link to the online poll was first provided to around 500 people, and some of the participants sent this survey to other experts in the construction business. Because the link was shared with the participants' coworkers, the response rate may not be precise. The main survey was conducted to deduce the building stage divisions and the pertaining indicators. Test - retest method was used to check the consistency of the questionnaire survey results (De Zwart et al., 2002; Liebe et al., 2012). Around 30 experts out of the overall respondents were included in this procedure.

4.3 DATA ANALYSIS

The questionnaire study yielded 123 valid respondents. Various stakeholders from construction industries were included in the sample, including green building consultants, service engineers, architects, constructors, structural engineers, cost engineers, and academicians. Lawyers, property managers, secretaries, and construction workers were among the others. These eight groups each have professional knowledge and experience in green building research, and their insights on sustainable evaluation models and techniques were highly useful to the study. The questionnaire survey was organized into three sections: background information, generic questions on the appraisal of sustainable buildings in India, and data for model development. Questionnaire surveys sample can be found in Appendix I was used in the study. The overall context of the questionnaire survey will be described in the next section.

4.3.1 General background of the participants

The responses obtained from the main questionnaire survey were more than 123. The participants in this questionnaire survey included: green building consultants, architects, cost engineers, contractors, structural engineers, service engineers, and academicians as shown in Figure 4.1. Among these participants, around 40% of them had work experience of more than five years.

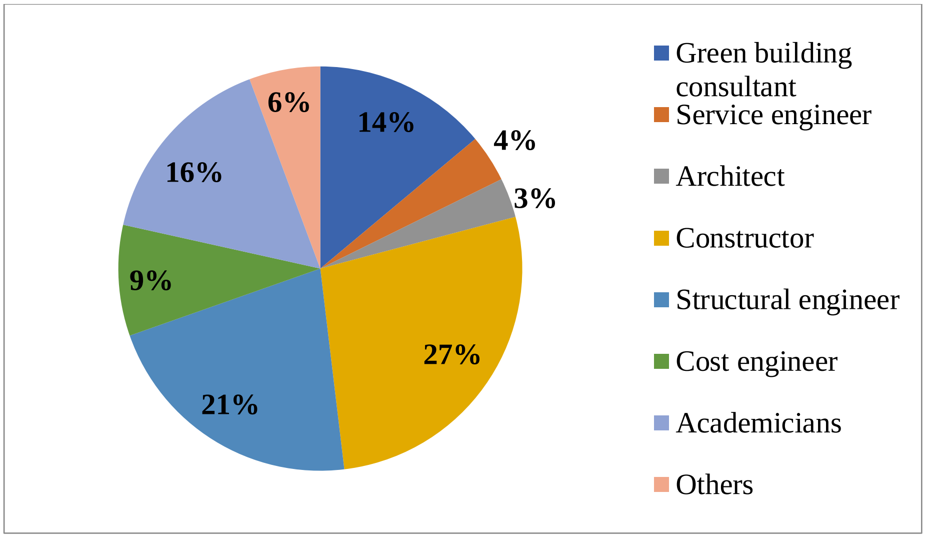

Figure 4.1: Participants in questionnaire survey

4.3.2 Sustainable building development in India

Experience of experts was reviewed and a questionnaire survey was prepared which comprises questions regarding the present condition of sustainable building development and assessment in India. The gaps in the present assessment tools especially in India were identified from the literature survey. Updating the present condition of sustainable development in India becomes vital as the construction sector is developing at a faster rate in India. Three questions were framed in this part, details included in Appendix I.

The respondents were asked to answer the survey by comparing the current state of Green Building (GB) development in India with the development found in western countries. Participants who felt that there is a lag in sustainable development in India were also asked to quote the possible reasons for the same. They were also asked to suggest ways of improving the situation. The participants included experts from a variety of disciplines in the construction business, and they represented a diverse range of perspectives and requirements on the development of green buildings in India. Considering their viewpoints regarding the limitation in the development of green buildings and ways to improve this situation is an added advantage for the study. When asked about the current situation of green buildings current in India compared to other developed and developing countries, about 73% of the participants opined that the green buildings trend has just started and is slowly developing in India. About 5% of the participants stated that it has not started yet, and around 11.5% thought that it has just started and is developing very fast and the remaining 11.5% of the participants opined that it is entering a developed stage as shown in Figure 4.2. This indicates that the concept of green building practices in India is here for about 100 years, but it has not yet earned enough appreciation from the public and private sectors of the construction industry.

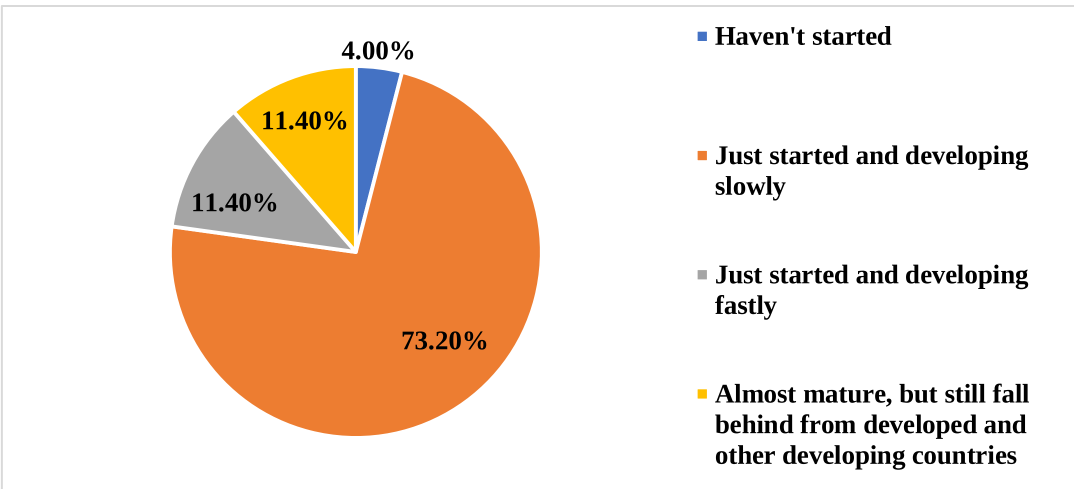

Figure 4.2: Present situation of sustainable building development in India

The reason for this situation is also discussed in the study. Participants who felt that there is a lag in sustainable development in India compared to western countries were asked to quote the possible reasons for the same and rank them. Countries like China and India are developing at the same phase with similar populations and trends in sustainable buildings. The reasons for the slow development of sustainable building construction in India will consider the same factors as in China drawn from literature review (Dexiang, 2006; Kai and Wang, 2011; Tian et al., 2012; Vyas and Jha, 2016; Vyas and Jha, 2018), such as:

- Lack of professional consciousness
- Lack of funds

- Technology constraints
- Building material constraints
- Others

Participants in this poll were asked to evaluate the level of relevance according to a scale from one to five (1 = most, 5 = least). The participants were requested to rank the factors. While considering the responses of the participants 0 indicates that no factor was selected, 1 indicates that the participants preferred the first reason, 2 indicates that the participants preferred the second reason, 3 indicates that the participants preferred the third reason, 4 indicates that the participants preferred the fourth reason, 5 indicates that the participants preferred the fifth reason and so on. Each factor's total weight is computed, and a Relative Importance Index (RII) is calculated to indicate the relevance of these concerns. In this study, the RII is used to determine the relative importance of the indicators. In this question, RII is used to rate the problems that contribute to India's delayed acceptance of sustainable building.

$$\mathbf{RII} = \frac{\boldsymbol{\Sigma ai * xi}}{\mathbf{A * N}} \qquad \text{………... Eq. 4.2}$$

Where,

ai = constant expressing the weight of the i^{th} response,

xi = level of response given as a percentage of total response for each factor,

A = highest weight,

N = total number of respondents.

4.3.3 Reasons causing lag in green building construction in India

In order to know the possible reasons why they perceive India is falling behind western countries, the participants were asked to select and rank among the possible reasons that were obtained from the literature survey. To analyze the results, RII was used.

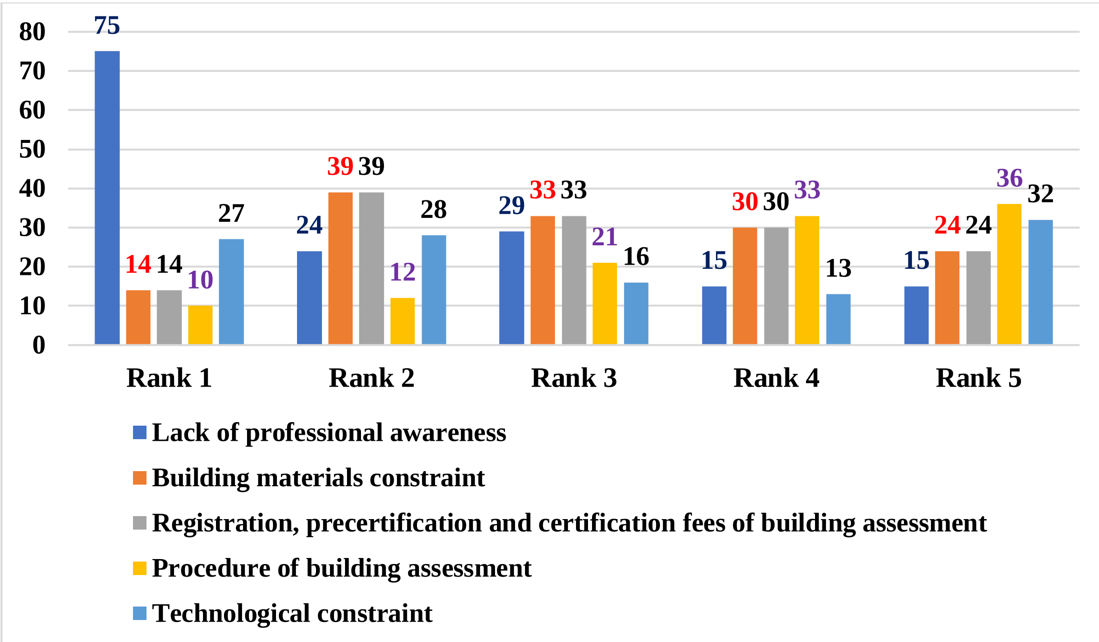

Figure 4.3: Reasons causing the lag in green building construction in India

Figure 4.3 indicates the responses of the participants obtained from the survey-based on the questionnaire indicating the reasons for the fall behind of green building concept in India compared to other western countries. The results are used in deriving the RII and thereby ranking them as shown in Table 4.1.

Table 4.1: Ranking of lag in green building construction in India

Reason	RII	Rank
Lack of Professional awareness	0.76	1
Technological constraints	0.61	2
Building material constraints	0.58	3
Registration, Precertification and certification fees	0.56	4
Procedure of building assessment	0.47	5

4.3.4 Methods to improve green building situation in India

From Table 4.1, it is evident that the major reason why India falls behind western countries in terms of green buildings is due to lack of professional awareness followed by the technological and building material constraints and also, the registration, pre-certification, and certification fees, and the procedures were involved. Some of the other reasons from the respondents include the lack of initiative, unwillingness to accept new technology, increased construction costs due to green building friendly materials, and the problems with respect to the adaption of changes to the existing engineering plan. As for the solution to this situation, the following results were obtained from the questionnaire survey.

Figure 4.4 indicates the responses of the participants obtained from the questionnaire survey as the solutions that can be implemented to alleviate the green building concept in India. The results are used in deriving the RII and thereafter to rank them as shown the Table 4.2.

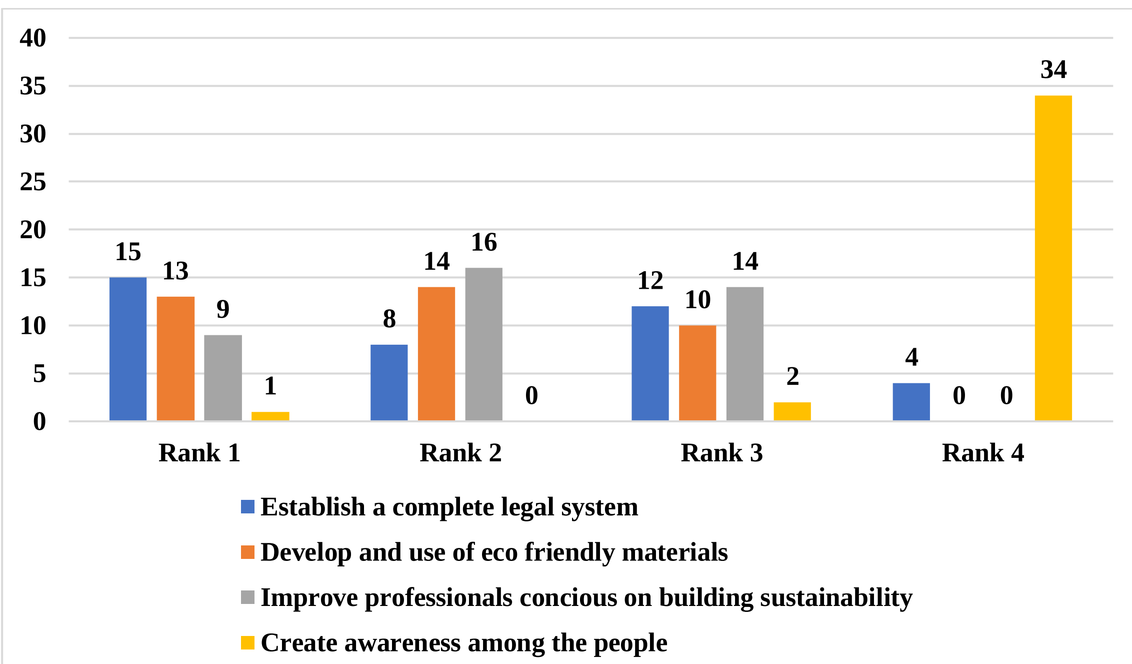

Figure 4.4: Improvement of green building situation in India

Results from Table 4.2 shows that the possible ways that can be implemented to improve the green building situation in India include developing and using eco-friendly materials, improving the professional consciousness, establishing a complete legal system, and creating awareness among the people. Other suggestions from the survey participants included establishing consciousness among the public towards the use and development of eco-friendly and sustainable materials, establishing an assessment tool that suits purely the Indian context and ensuring tax benefits for those who take the initiative towards the inclusion of sustainable construction concept in their buildings.

Table 4.2: Ranking for the improvement of green building situation in India

Factors	RII	Rank
Develop and use eco-friendly materials	0.77	1
Improve professional's consciousness of building sustainability	0.72	2
Establish a complete legal system	0.71	3
Create awareness among the people	0.28	4

4.3.5 Building stage divisions

According to literature studies, there are several methods for building stage division. Some span the whole life cycle of a structure, while others do not. Many researchers prior studies on building performance evaluation used various forms of division based on their own goals and areas. As discussed, the four-stage divide is an appropriate method for assessing sustainability throughout the development phase of building, which encompasses inception and design, construction, operation, and demolition. Concerning the impact of regional differences on the performance of building evaluation, it is critical to undertake an industry study to explore the common acceptance stage division by professionals in India. Thus, in this phase, participants were asked to pick the most appropriate building division stage based on their knowledge and experience. Among 123 professionals, about 45% chose inception and design, construction, operation, and demolition as building stage divisions refer to Figure 4.5.

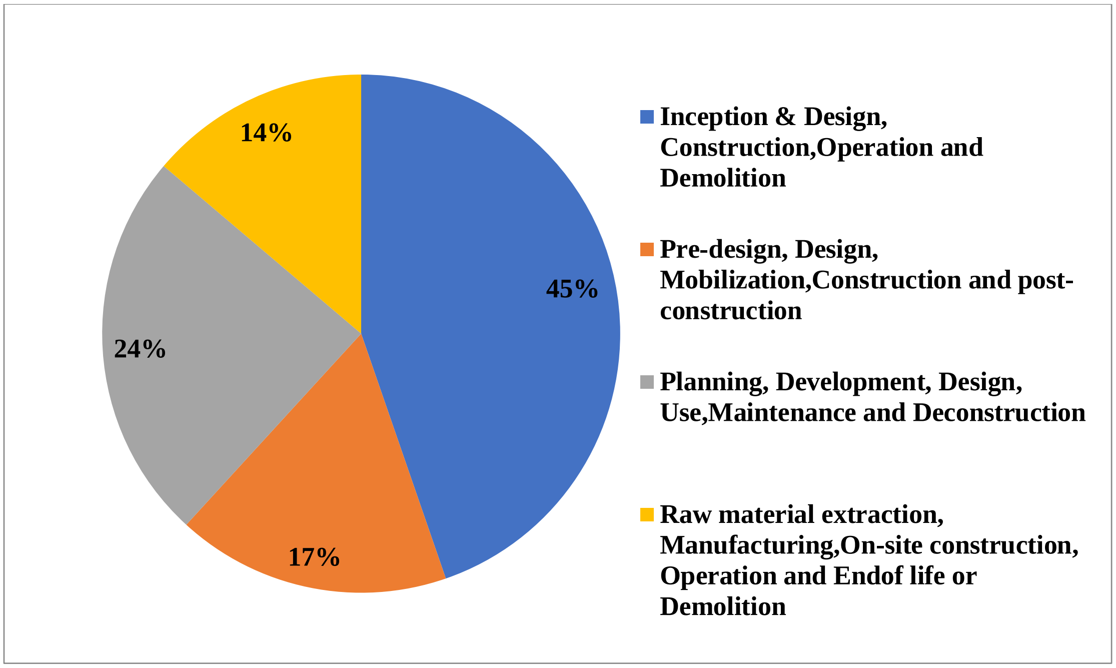

Figure 4.5: Building stage divisions

4.3.6 Pillars of sustainable impacts

The first stage in developing an evaluation model for building sustainability is to identify the pillars that must be considered in a building's long-term sustainability. According to the theoretical foundation and previous researchers' work, three pillars, including environmental, economic, and social aspects, must be examined. As discussed, regional differences have a significant impact on building sustainability assessment, and the goal of this study is to establish a flexible assessment tool for buildings in India. Most Indian professionals do not have the same views as those in the literature study, therefore gathering information from those in the Indian construction business is critical. According to the survey results, 97 participants (78.9%) identified environmental, economic, and social impacts as the most important factors affecting a building's life cycle performance as shown in Figure 4.6, which is consistent with the literature evaluation. In accordance with the literature review, these three impacts will be used to evaluate building sustainability performance in the model.

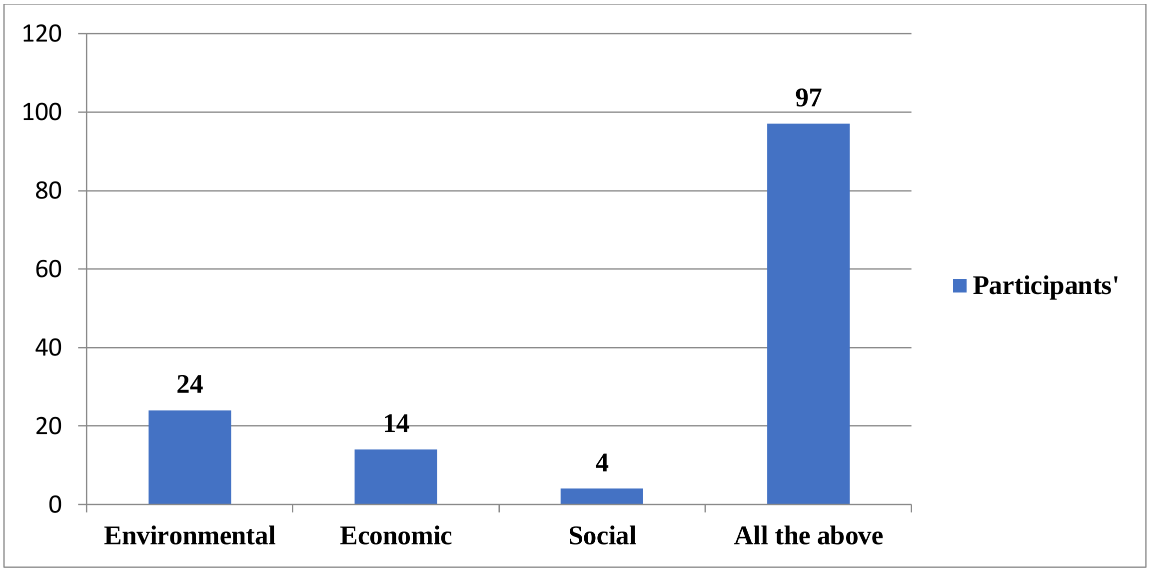

Figure 4.6: Pillars of sustainable impacts

4.3.7 Test-Retest method

In the test-retest method, which was conducted to verify the reliability of survey results, around 30 participants were asked to fill the same questionnaire survey form for the second time. It showed a strong correlation between the test and retest methods with the coefficients as indicated; Q1 (0.98), Q2 (0.87), Q3 (0.95), Q4 (0.86), Q5 (0.95), Q6 (0.99), Q7 (0.76), Q8 (0.62), Q9 (0.72), Q10 (0.96), Q11 (0.98), Q12 (0.98), Q13 (0.95), Q14 (0.82), Q15 (0.96), Q16 (0.98), Q17 (0.98), Q18 (0.98) [Values in the brackets indicate the correlation values]. All questions have met the reliability threshold of $r > 0.71$ (for strong correlation), found using Pearson's coefficient of correlation (Table 4.3). Therefore, the survey result was proven to be reliable.

Table 4.3: Pearson's coefficient of correlation

Coefficient, r	**Interpretation**
0.00 – 0.10	Negligible correlation
0.10 – 0.39	Weak correlation
0.40 – 0.69	Moderate correlation
0.70 – 0.89	Strong correlation
0.90 – 1.00	Very strong correlation

Source: (Schober and Schwarte, 2018)

4.4 ADDITIONAL INDICATORS AND THEIR ATTRIBUTES ADOPTED IN THE MODEL

As discussed in Section 2.5, some additional indicators have been adopted in the study. To understand the importance of these indicators in the assessment process, the participants were asked in the questionnaire to provide the importance of each indicator. The result of the survey is as follows: Figure 4.7 shows that 99% of the survey participants have marked topographical and climatic conditions in assessment as an important factor to be incorporated into the assessment model. Figure 4.8 indicates that almost all the participants have marked construction workers' health and safety in assessment as an important factor to be incorporated into the assessment model. The graphical representation in Figure 4.9 shows that all the participants have marked Project Management Consultancy (PMC) in assessment as an important factor to be incorporated into the assessment model. Figure 4.10 shows that 98% of participants have remarked operation and maintenance costs as an essential factor to be considered in the assessment model for evaluating sustainability. Figure 4.111 indicates almost all the participants have indicated risk management measures costs in assessment as an essential factor to be included in the assessment model. Figure 4.12 represents that, 98% of participants have marked security measures in assessment as an essential factor to be incorporated in the assessment model. Figure 4.13 shows all the respondents have indicated domestic and solid waste segregation and management in assessment as an important indicator to be included in the assessment model.

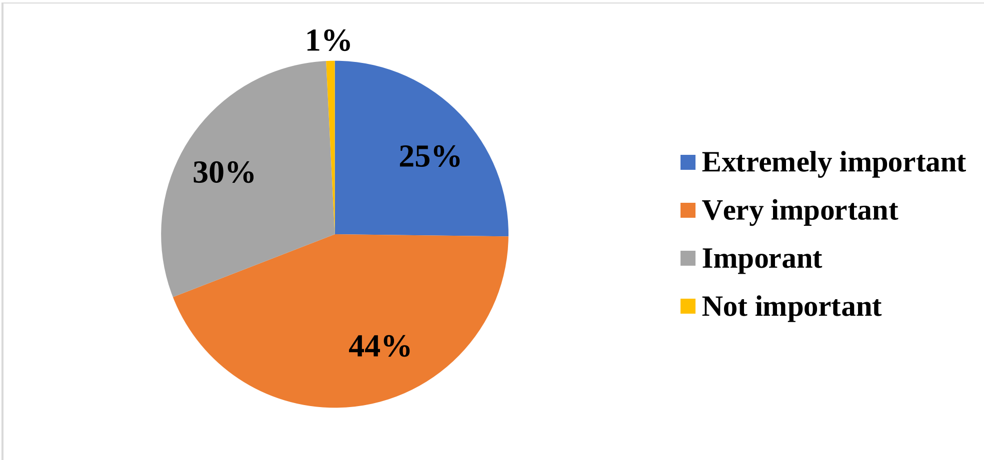

Figure 4.7: Topographical and climatic conditions in assessment

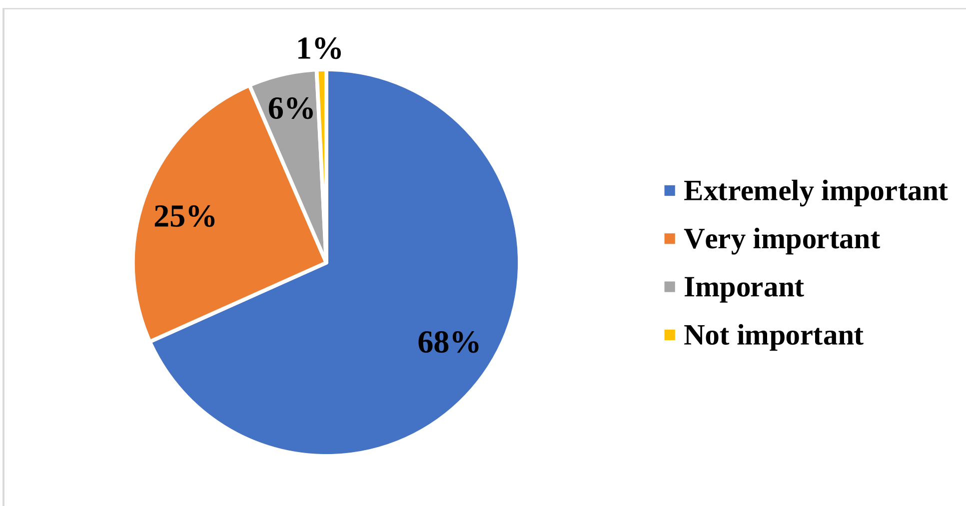

Figure 4.8: Construction workers health and safety in assessment

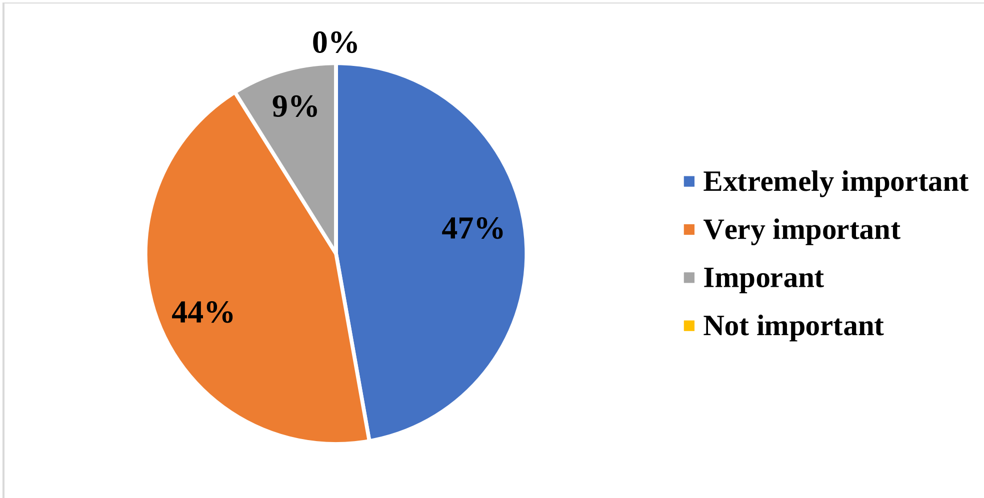

Figure 4.9: Project management consultancy in assessment

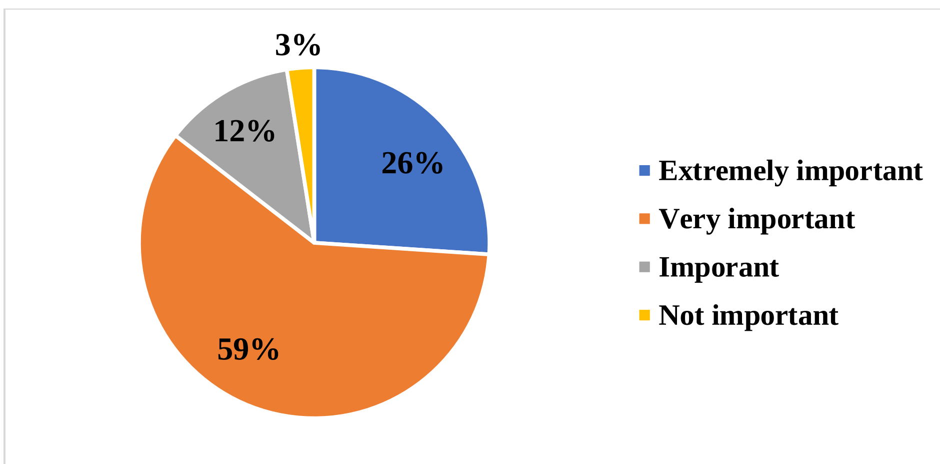

Figure 4.10: Operation and maintenance costs in assessment

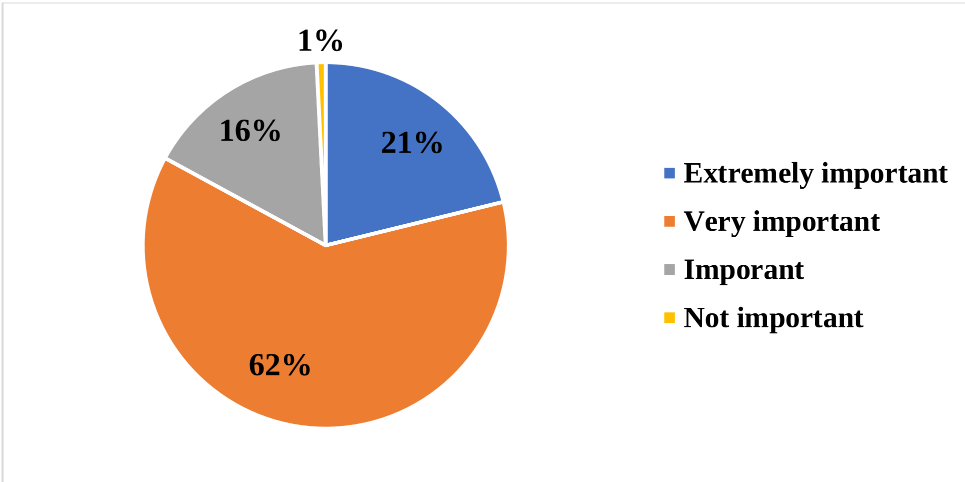

Figure 4.11: Risk management measures costs in assessment

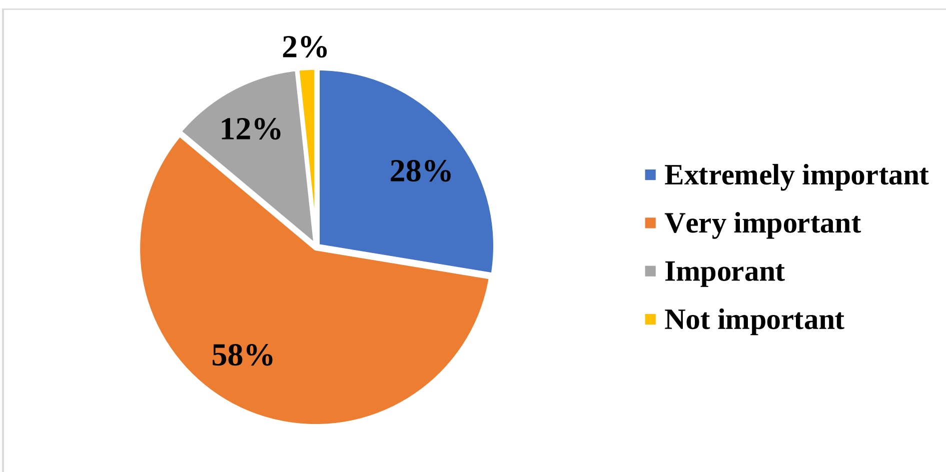

Figure 4.12: Security measures in assessment

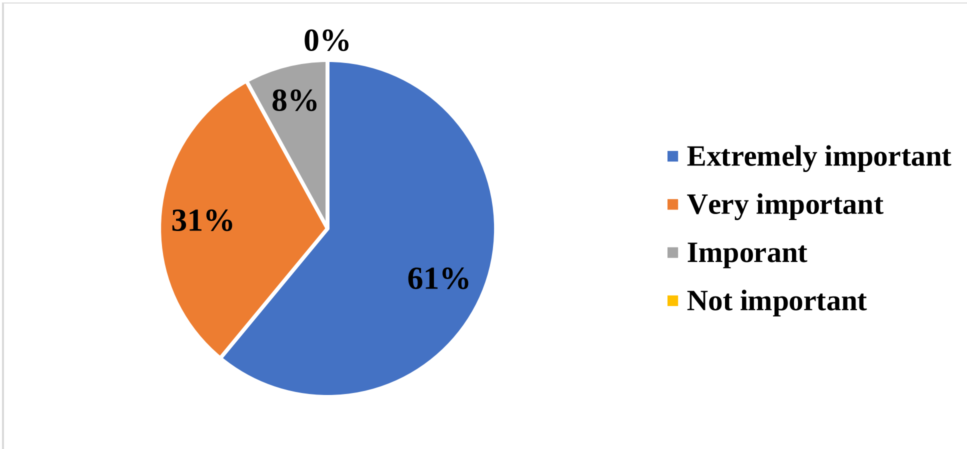

Figure 4.13: Domestic and solid waste segregation and management in assessment

4.5 ASSESSMENT INDICATORS IN THREE PILLARS IN BUILDING DIVISION

The present study's goal is to assess building performance at various stages, it's critical to define indicators at each stage in three pillars. Assessment indicators based on India's situation were created for the questionnaire survey. Because the four divisions of the building development have already been established in the previous sections, the assessment indicators are reviewed in each division. Table 4.4 shows the assessment indicators for the four stages, which are based on survey results and literature study.

Table 4.4: Assessment indicators in three pillars in building stages

Pillars / Stages	Environmental	Economic	Social
Inception and design	Sustainable site Sustainable materials Sustainable design Heritage conservation Topographic and climatic conditions	Land cost Project management and consultancy charges Other costs and charges	Impact on community Accessibility to public transport and other facilities Urban integration Cultural issue
Construction	Resource Energy Waste Water Emission Noise	Construction cost PMC charges Other costs and charges	Impact on community Construction workers health and safety Construction risk management measures
Operation	Resource Energy Water Emission Domestic and solid waste segregation and management	Operation cost Maintenance cost Occupancy cost	Occupants health and safety Occupiers satisfaction and productivity Stakeholder relations Security measures Risk management measures
Demolition	Waste Emission Noise	Demolition cost Salvage value Other costs and charges	Impact on community Health and safety

4.6 SUMMARY

This chapter starts with a discussion of India's current condition, based on responses from 123 people who took part in a questionnaire survey. The slow growth of sustainable construction and building evaluation in India, as well as the need for an appropriate assessment system, which is consistent with the findings of the literature study, underline the importance of this research. This study also examines the existing assessment tools. Most significantly, the stage division is determined upon, as are the essential indications in each stage in three pillars. These elements will serve as the foundation for the model growth in the next chapter.

CHAPTER 5

DEVELOPMENT OF BUILDING PERFORMANCE SCORE MODEL

5.1 INTRODUCTION

A model for assessing the sustainability performance of buildings has been created based on the literature review and industry survey and is presented in this chapter. The model is known as the Building Performance Score (BPS). The process of establishing indicators is described, followed by a comprehensive examination of these indicators. For the evaluation of indicators, both quantitative and qualitative approaches were employed. Several techniques were chosen in this study based on a survey of the literature on existing evaluation methods for these parameters. LCA measured the key environmental indicators, whereas LCC quantified the economic indicators. A Value Score (VS) was used to measure social factors. The defined approaches for these indicators have been considered in phases. The weighting of each indication was then determined. The importance of the indicators in relation to one another was determined using the Analytic Hierarchy Process (AHP) method.

5.2 MODEL DEVELOPMENT

The phases of the building and the connected indicators in each stage of construction inclusive of all the sustainability pillars were developed based on the results of the survey. This model has four subdivisions of the building life cycle. Each division consists of the assessment indicators pertaining to the TBL of sustainability that analyzes the building performance in accordance with the environmental, economic, and social aspects. The indicators, topographical and climatic conditions, construction workers' health and safety, project management consultancy charges, operation and maintenance costs, security and risk management measures, and domestic waste segregation and management were accepted as per the expert's opinion and are incorporated in the present model. However, in every phase of building development, assessment indicators for three pillars have been identified. A conceptual model of BPS is developed and is represented based on these key indicators as shown in Figure 5.1.

For decision making, all the sub-models were analyzed with respect to three pillars of sustainability to measure their impacts during the various development phase of the building. The model is integrated to provide a unified decision-making framework that accounts for the sustainability implications of all main operations throughout the project. There are three stages in the BPS model. The first stage comprises the life cycle of the building which is further classified into different phases such as inception and design, construction, operation, and demolition. The second stage contains sustainable pillars for all the stages. In each of these phases, the impacts of three pillars in sustainability were included. The last stage contains the assessment indicators.

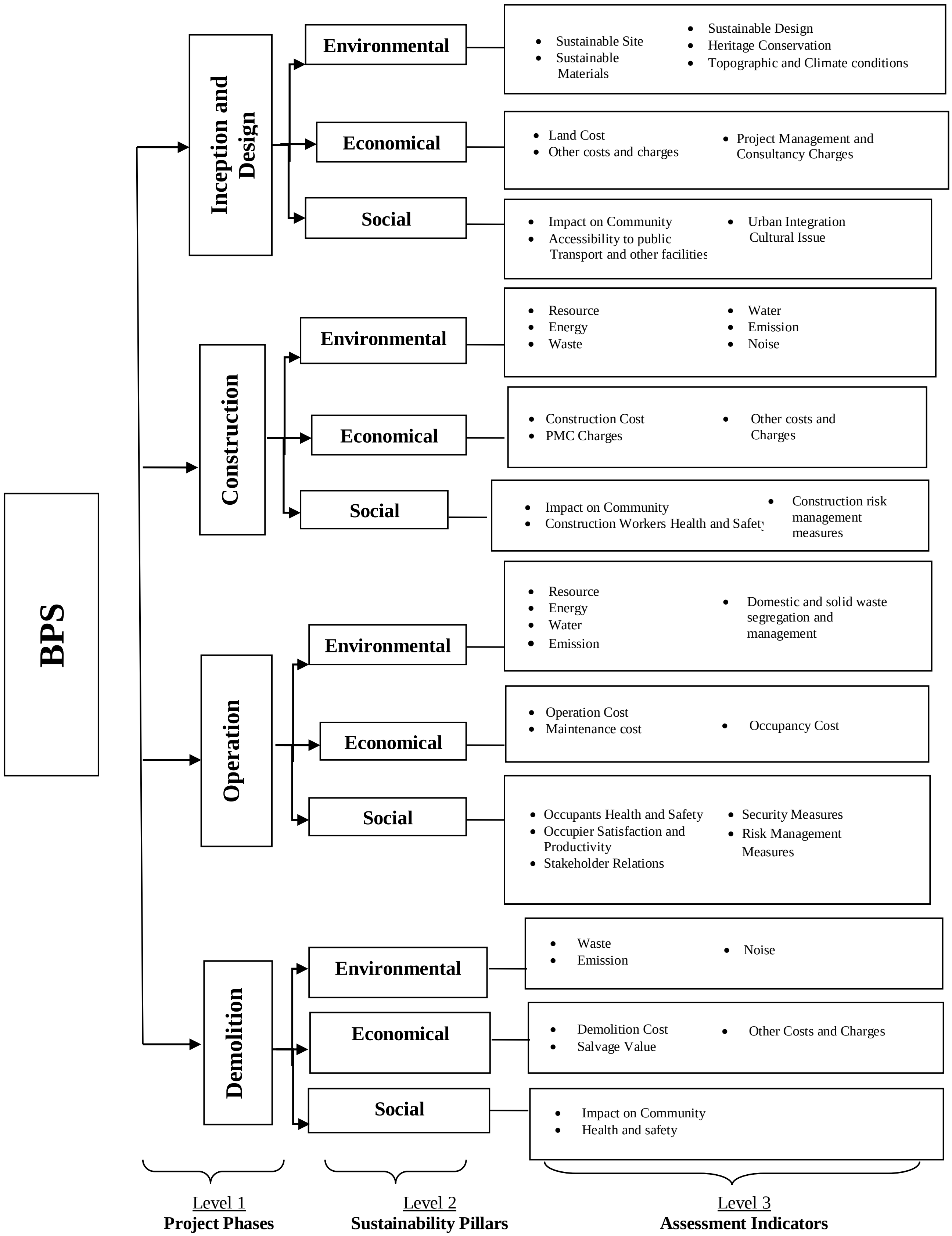

Figure 5.1: Building Performance Score conceptual model

5.3 EVALUATION OF INDICATORS

After the development of a conceptual model, the indicators are to be evaluated with respect to a building project. Among the total 44 indicators identified in the model, different methods of evaluation were used in the present context.

5.3.1 Assessment details of indicators

These indicators are investigated using LCA, LCC, and VS. According to the debate, subjective concerns are quantified using VS which aims to optimize their subjective qualities. LCA is used for objective aspects of environmental challenges, while LCC is used for economic aspects. The criteria and technique for the assessment indicators in the inception and design stage are listed in Appendix IV. The indicators were chosen based on a review of literature and an assessment of the evaluation specifics of sustainable performance methods used both locally and globally. For example, in the inception and design stages, a sustainable site is one of the environmental indicators. These indicators criteria include whether it's a green field or a brown field, as well as if it takes habitat conservation into account.

Similarly, the criteria and procedure for the assessment indicators in the construction stage, operation stage, and demolition stage are listed in Appendix V, Appendix VI, and Appendix VII respectively. The energy consumption in the construction stage, for example, includes both embodied and on-site energy. LCA is used to assess the environmental indicators at this stage. The primary economic aspects at this time are the construction costs. For example, building costs, which comprise labour, construction materials, utilities, equipment costs (rent or buy), and financing and services costs. LCC is a tool for assessing economic indicators. Likewise, LCA is used to assess environmental indicators, LCC is used to assess economic indicators, and VS is used to determine social indicators in the operation and demolition stage.

Each indicator in the three pillars in each stage is defined and assessed in depth in Appendix IV, Appendix V, Appendix VI, and Appendix VII. These criteria guide the quantification and qualification of indicators. The evaluation of indicators will be covered in detail in the next section. The manner in which VS, LCC, and LCA are conducted is also explained.

5.3.2 Evaluation methods

In total there are 44 indicators out of which, there are 19 environmental indicators, 12 economic indicators, and 13 social indicators. In this part, the various methods for assessing indicators, such as LCA, LCC, and VS are addressed in detail.

i) Life Cycle Assessment (LCA)

LCA of a building is more appropriate for addressing the environmental aspects in construction, operation, and demolition stages. It helps to identify and quantify the inputs and outputs of the potential impacts of a building on the environment. The quantity of energy consumption in mega joules (MJ), water and materials consumption in kilograms (kg), waste generation in kilograms (kg), and GHG emissions are all evaluated using this method. While calculating the scores for each indicator, all the values are converted into a common standardized value using the standardization approach.

The energy consumption is calculated from the energy consumption on-site, the material that consumes energy during the phase of operation, and the type of equipment used. Other factors like running time and wastage affect the average consumption of power. The consumption of water is calculated for the construction and operation stages. In the construction phase, the water used on site for various purposes like construction activities, equipment, workers, and fire protection are considered. Whereas in the operation phase, water consumed for domestic use, equipment, and irrigation purposes are included. The material consumption from the construction and operation stage is deduced from the Bill of Quantities (BOQ). The total quantity of waste generated is calculated by the summation of construction waste and garbage produced on site. GHG emissions quantity in the construction, operation, and demolition stage is calculated by multiplying the material quantities with the CO_2 coefficients. The coefficient of CO_2 emissions depends upon the inventory of carbon and energy (Cabeza et al., 2014).

ii) Life Cycle Costing (LCC)

Achieving sustainability norms in the construction of building is not the only factor that is to be considered but cost-effectiveness in construction is also important. Understanding the economic impact of any construction project on society before commencing the project is essential. LCC method is adopted to understand the complete cost incurred in the complete life cycle of building (Hajare and Elwakil, 2020). A comparative assessment of cost over a definite period of time can be done by using the LCC technique. All the economic factors are considered in ISO-15686, including initial and future operational costs (Pelzeter, 2007). All the costs such as capital, operation, maintenance, and replacement costs are put up in such a way that can be compared and a single picture which shows that all of these costs incur at different phases in the building life cycle. Because of this, a comparison between different design options can be done and the design which has optimum value can be selected to invest in. The soundness and effectiveness of LCC method make this method suitable to be used within construction industry for practical application and implementation (Olubodun et al., 2010). This methodology is being used in recent times in order to assess the economic performance of the building.

iii) Value Score (VS)

This assessment evaluates the social component of sustainability at every stage of the life cycle of building (Fortier et al., 2019). There are different methods for sustainability measure of the subjective indicators. For example, a four-level rating score range from 0, 1, 3, 5 (Gangolells et al., 2009); a five-level value score of 1-5 (Ding and Shen, 2010), and another five-level value score from -2 to +5 (Alwaer and Clements-Croome, 2010). Among these three types of values score, the four levels and the five levels of 1-5 do not contain a negative level. The building industry brings many negative impacts such as environmental, economic, and social. It would be insufficient to have a value score just having the positive aspects. In that case, the values in the range from -2 to +5 (Alwaer and Clements-Croome, 2010) are adopted in this research. The evaluation is purely made based on the information obtained from a panel of experts and stakeholders of the building involved. Details of the VS assessment are provided as shown in Table.5.1.

Table 5.1: Value Score performance evaluation

Score	Performance Evaluation
+4 ≤ +5	Best practice (excellent performance)
+3 ≤ +4	Very good practice reflecting stable conditions in terms of sustainability
1.5 ≤ +3	Good performance
0 ≤ 1.5	Current standard (Minimum acceptable standards) or typical practice for particular type of building and region.
-2 ≤ -1	Unsatisfactory performance (Deficient) which is not likely to meet the norms and the designed criteria and has negative impacts on the environment in social, economic and environmental terms.

5.4 WEIGHTING OF INDICATORS

To indicate the preference of some indicators over others, weighting is required. Each indicator can be weighted in a variety of ways. It can be classified into two groups in general: the objective category and the subjective category (Yang et al., 2010). Methods such as Delphi, AHP, simple rank order, and ratio weighting can be used to value indications in the subjective category (Yang et al., 2010). The decision-maker can use these strategies to make a prediction about the relative value of the indications. Delphi is a systematic interactive forecasting method by an expert panel, and it is one of the most often used methods in this group. It results in a group decision, but it is time-consuming because it takes two or more rounds to reach a consensus. The importance of group decision-making is that it removes subjective judgment from an individual perspective. The AHP approach is another method in this group. Saaty (1983) established a systematic decision-making framework for tackling multi-criteria decision issues of choice and prioritization. The AHP method, like Delphi, can be used to create group choices, but with only one round. As a result, the procedure takes less time and costs less money (Vidal et al., 2011). AHP was used to determine weightings for indicators in the model based on the study time and procedure. AHP is used weighting of indicators is necessary to signify the choice of importance and significance of some indicators over others. It is typically a framework for systematic decision-making used in solving multi-criteria decision problems of prioritization and choice (Toossi et al., 2013; Kumar et al., 2017). This method gives a group decision in a single round requiring less time and lower costs. A mathematical solution can be developed by a step-by-step framework in AHP to determine weightings and priority by using pair-wise comparisons. Figure 5.2 shows the flow of the AHP method.

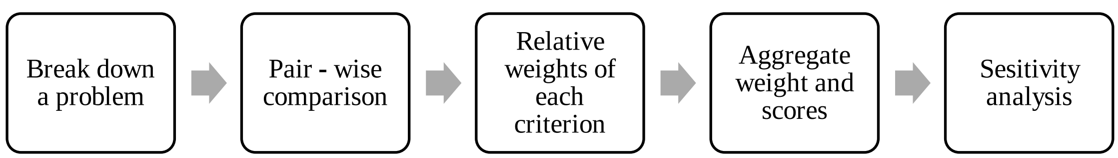

Figure 5.2: The flow of AHP method (Source: Saaty, 1983)

A scale of 1 - 9 (1=Equal Importance; 3=Moderate Importance; 5=Strong Importance; 7=Very Strong or Demonstrated Importance; 9=Extreme Importance; and values 2,4,6,8 indicate Intermediate values) is used to define the relative importance of one indicator with the other. This method was chosen for the reason that it takes into account the decision-makers interests and their expertise, which is considered crucial for calculating the weightings. In this method, the individual opinion is converted into a group judgment and the geometrical mean is obtained. This method maintains the reciprocal property of the judgment matrix (Vyas et al., 2019a). The comparison matrix done pair wise from each individual is established as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \qquad \text{.......... Eq. 5.1}$$

The comparison matrix obtained by combining the individual matrix is established as follows:

$$A = \begin{bmatrix} \sqrt[k]{a_{11}^{1} \times a_{11}^{2} \times,,,,,,,,,,\times a_{11}^{k}} & \sqrt[k]{a_{12}^{1} \times a_{12}^{2} \times,,,,,,,,,,\times a_{12}^{k}} & ,,,, \sqrt[k]{a_{1n}^{1} \times a_{1n}^{2} \times,,,,,,,,,,\times a_{1n}^{k}} \\ \sqrt[k]{a_{21}^{1} \times a_{21}^{2} \times,,,,,,,,,,\times a_{21}^{k}} & \sqrt[k]{a_{22}^{1} \times a_{22}^{2} \times,,,,,,,,,,\times a_{22}^{k}} & ,,,,, \sqrt[k]{a_{21}^{1} \times a_{21}^{2} \times,,,,,,,,,,\times a_{21}^{k}} \\ \sqrt[k]{a_{n1}^{1} \times a_{n1}^{2} \times,,,,,,,,,,\times a_{n1}^{k}} & \sqrt[k]{a_{n2}^{1} \times a_{n2}^{2} \times,,,,,,,,,,\times a_{n2}^{k}} & ,,,,, \sqrt[k]{a_{nn}^{1} \times a_{nn}^{2} \times,,,,,,,,,,\times a_{nn}^{k}} \end{bmatrix} = \lambda_{max} W$$

……..Eq. 5.2

Where, λ_{max} is the maximum Eigen value of a comparison matrix

W are the weightings for each of the indicators

Consistency test is conducted after the Eigen value calculation to test whether the results are acceptable or not. When consistency ratio is less than 0.1, the results are acceptable; else, a new comparison matrix is required to weigh the indicators.

Consistency ratio $\text{C.R.} = \frac{\text{C.I.}}{\text{R.I}}$ ……..Eq. 5.3

C.I. is the consistency index and is calculated using the formula,

$\text{C.I.} = \frac{\lambda\text{max} - \text{n}}{\text{n} - 1}$ …….. Eq. 5.4

Where,

λ_{max} is the maximum Eigen value of a comparison matrix

n is the number of indicators considered for assessment

R.I. is the random index obtained from Saaty’s table (Refer: Table 5.2).

Table 5.2: Saaty's table

Matrix size	Random consistency index (RI)
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57

The indicators obtained can contain scores with different units because they can be either quantitative or qualitative. The scores are converted to a single dimension or a dimensionless unit to make them comparable. The following formula is used to get a standardized score.

$$\text{Standardized score S} = \frac{\text{Obtained Score (S)} - \text{Minimum Score (S min)}}{\text{Maximum Score (S max)} - \text{Minimum Score (S min)}}$$

…….Eq. 5.5

After the scores are standardized, the BPS is mathematically formulated as,

$$BPS = \sum_{i=1}^{n} W_i \, S_i$$ …….Eq. 5.6

Where, W_1 represents the weightings of indicators in each phase obtained from the Analytical Hierarchy Process. S_1 indicates the sustainable scores in the phases of inception, design, construction, operation, and demolition obtained from LCA, LCC, and VS survey. Building Performance is calculated in all the life cycle stages as below:

$$BPS_{inception\ and\ design} = \sum_{i=1}^{n} W_i\, S_i\,, \qquad BPS_{construction} = \sum_{i=1}^{n} W_i\, S_i\,,$$

$$BPS_{operation} = \sum_{i=1}^{n} W_i\, S_i\,, \qquad BPS_{demolition} = \sum_{i=1}^{n} W_i\, S_i\,,$$

……. Eq. 5.7

BPS = BPS $_{\textbf{inception\& Design}}$ + BPS $_{\textbf{construction}}$+ BPS $_{\textbf{operation}}$+ BPS $_{\textbf{demolition}}$ ……. Eq. 5.8

The final and overall BPS score for the building is calculated by the weighted summation of the scores obtained in each stage as shown below. It is believed that the higher the score, the better the building sustainability performance.

5.5 SUMMARY

This chapter focuses on the development of the BPS model. For indicator evaluation, LCA, LCC, and VS are used. For each step of construction, four sub-models are established. The sustainable score at each stage is constituted of environmental, economic, and social factors. The BPS indicates the overall performance score. The AHP method is used to construct the model weightings. Three case studies are selected for model verification in the next chapter. The sustainable performances of the case studies at different stages of construction, as well as the overall outcomes, are reviewed.

CHAPTER 6

CASE STUDIES AND MODEL VERIFICATION

6.1 INTRODUCTION

In this chapter, three case studies are considered to verify the model developed in the previous chapter, which deals with the development of a model for assessing sustainable buildings. Two government office buildings and a corporate office which are certified green buildings are being considered for the study. The BPS model is adopted to assess buildings for their sustainability performance. Along with sustainability performance assessment of the buildings at every stage of their complete life cycle, the overall performance of the buildings is also analyzed. For the assessment of indicators both qualitative and quantitative methods are used. The calculation process of the indicators converses in this chapter. For generating the weightage, an AHP survey is used and a panel of experts was also recruited for the survey. The results of the sustainability performance of the three buildings obtained from the BPS model are compared with the LEED-certified score for further discussion.

6.2 GENERAL INFORMATION OF THE THREE CASE STUDIES

Several factors were considered when choosing a project to verify the model, including the project’s location, size, and type. Three different projects that satisfy the conditions were selected for the comparison analysis. The buildings considered are office buildings located in different cities in India which are green building certified. Case study 1 was an office building located in New Delhi; Case study 2 was an office building located in Gulbarga; Case study 3 was a corporate office and training center in Pune. The details of the case studies are discussed here.

6.2.1 Case Study 1 - Indira Paryavaran Bhavan, New Delhi.

Indira Paryavaran Bhavan is a Ministry of Environment and Forests project for constructing a new office building at Aliganj, JorBagh Road, New Delhi. The basic design concept of the project is to make the net-zero energy green building. The building is targeted to achieve LEED India Platinum Rating and GRIHA 5-star rating. The building is intended to be a state-of-the-art landmark with a focus on the conservation of natural areas and trees in order to reduce harmful environmental effects, provide adequate natural light, create shaded landscapes that reduce ambient temperatures, maximize energy-saving systems, and minimize operating costs by adopting green building concepts. The construction was also expected to achieve conservation and optimization of water requirements including reuse of water by recycling the waste. The building was also expected to be friendly to physically challenged people.

The total cost of the project was estimated to be Rs.128.63 crores. The revised cost was projected to be Rs. 201.49 crores due to the subsequent increase in the scope of work. The building is an RCC framed structure with 3 basements and two blocks one of Ground+6 and another of Ground+7. The total plot area is 9565.13 m^2, the basement area is 11826 m^2, the super structure area is 19088 m^2 and the total plinth area is 30914 m^2. Many energy conservation measures were adopted to optimize the overall design load. High-efficiency solar panels were planned to achieve Net Zero energy building. Energy-efficient T-5 and LED fixtures innovative chilled beam system were used for cooling. Pre-cooling of fresh air from toilet exhaust using a heat recovery wheel was used in order to reduce the load on the chillers plant. Water-cooled chillers and double skin air handling units with variable frequency drives were planned to be installed. Geo thermal heat exchange technology was also planned for heat rejection from the air-conditioning system. Innovative energy-saving regenerative elevators will be installed for the first time in a government building. Water conservation measures will be adopted in the building like low discharge water fixtures, dual flushing cistern, low demand plants in landscaping, drip irrigation system for green areas, make up the water tank for chillers plant, irrigation, and rainwater harvesting systems, which reduces the need for fresh water. The mechanized car parking will be provided in this building for the first time in the government office building to accommodate parking spaces for 344 cars.

6.2.1.1 Project scope

Initial scope: The five-star rated green building provides the following features:

- Basic Cost of Structure with W/S&SI and Electrical Installation.
- External Development.
- Two No's of capsule glass lift, four No's traditional passenger lifts, and one freight lift.
- Mechanized car parking for 344 Cars.
- Two No's silent type generator sets of 500 KVA capacities each.
- A UPS system with 30 minute-back up.
- 500 TR capacity air conditioning.
- Dry-type Electrical Sub Station with CO2 flooding.
- Security system controlled by CCTV.
- SPV solar generator.
- Solar water heater and lighting systems.
- Building Management System (BMS) for Optimum Energy Consumption.
- Automatic fire alarm with sprinkler system.
- Pressurized mechanical ventilation in the basement.
- Twin aviation obstructive lights.
- Power copper wiring.
- Telephone and Computer conducting.
- Pollution-free Facade lights.
- Sensors for energy and water saving.
- Dual piping System for recycling of used water.
- AHU with acoustic/fire check doors.
- PA system.

- Plasma screen for conference rooms.
- Eco Park and landscaping.
- Furniture for all office rooms conference halls and Cafeteria etc.
- Art work as per DUAC Requirement.
- Seismic Resistant Design.

Extended scope: In addition to the above, the following additional features are also provided in the building plan:

- Net Zero Energy building with 930 kWp Roof top Solar Power Plant.
- Audio Visual system in the auditorium and the committee room.

6.2.1.2 Site planning

- A plot measuring 9,565 m^2 was carved out of 7.4 Ha. of land for the construction of this new office building. (Site details refer to Table 6.1)
- The land falls in Zone-D of the Zonal Plan. Land use of the entire land as per MPD - 2021 was residential and this status was changed to Government office purpose for this piece of land. It is proposed to build GPRA on the balance portion of land.
- The site is surrounded on the eastern side by an NDMC housing colony and 15m. ROW, on West by 12m ROW and on North Lodhi Colony and 12m. ROW, on South GPRA colony of Aliganj.
- The Plot is easily approachable from Aurobindo Marg and Lodhi Road.
- A metro station "Jorbagh" is at a walkable distance of about 300m from this place

Table 6.1: Site details of case study 1

Development Controls	
Size of plot	9565 m^2
Maximum ground coverage	30%
F.A.R	200
Set backs	9m, 6m, 6m, 6m
Height	35m
Car parking	344

6.2.1.3 Water efficiency

- Use of curing compound.
- Low discharge fixtures.
- Dual Flushing cistern.
- Drip irrigation.
- Use of native species of shrubs and trees having low water demand in landscaping.
- Low lawn area so as to reduce water demand.
- Waste water treatment.
- Reuse of treated water for irrigation and cooling towers for HVAC.
- Rain water harvesting.

6.2.1.4 Energy efficiency

Various measures adopted in the building to achieve energy efficiency are as follows.

- Energy-efficient light fittings conforming to Energy Conservation Building Code, 2007 were used to reduce energy demand
- Water-cooled chillers and double skin air handling units with variable frequency drives.
- Part condenser water heat rejection by Geothermal Mechanism was used. This will also help in water conservation in cooling towers for HVAC systems.
- Integrated Building Management System (IBMS) was accepted for optimizing energy consumption, performance monitoring, etc.
- High-efficiency Cast Resin Dry Transformers were used for the electric substation. DG sets were used for captive power generation.
- Regenerative Lifts were included in the plan.
- Chilled beams save AHU/FCU fan power consumption by approximately 50 kW.
- Variable chilled water pumping system through VFD was used.
- VFD on cooling towers fans and AHU were used.

- Pre-cooling of fresh air from toilet exhaust air through a sensible and latent heat energy recovery wheel was used.
- The entire hot water generation was through Solar Panels.
- The usage of energy-efficient lighting fixtures was introduced with T-5 lamps.
- The usage of Lux level sensors to optimize the operation of artificial lighting.
- Control of HVAC Equipment & monitoring of all systems through IBMS.
- Solar-powered external lighting was used.
- On site, renewable energy systems with solar photovoltaic cells were used to meet total energy demand.

6.2.1.5 Materials

The materials used for the construction are listed below.

- Ready Mix Concrete with PPC having more than 30% fly ash content.
- Stone is available from the nearby area for flooring.
- Terrazzo flooring with locally available stone materials.
- Fly ash brick.
- AAC blocks.
- Jute bamboo-composite for door frames and shutters.
- UPVC windows with hermetically sealed double using low heat transmittance index glass.
- Use of high reflectance terrace tiles for low heat ingress.
- Avoided aluminium as it has high embedded energy.
- Grass paver blocks for ground water recharge.

6.2.1.6 Indoor air quality

The following conditions were adopted in order to achieve good indoor air quality:

- Use of low VOC paints.
- No smoking zone.
- Dust control and Noise control

6.2.1.7 Innovation and design

Various innovative designs were adopted in the building construction such as

- Geothermal heat rejection will also help in water conservation in cooling towers for HVAC systems.
- Chilled beam system for HVAC.
- Regenerative lift.
- High-Efficiency Solar panel to meet total energy demand.
- Mechanized car parking to optimize space and energy.
- Low energy EM technology for Bio digestion of organic waste.
- Solar passive design to reduce heat ingress in building envelope and allowing lighting to over 75% of indoor area.
- Three-level underground parking is provided for 344 numbers of cars. It is state-of-the-art mechanized parking to manage concentrated peak load during office hours.

6.2.2 Case study 2 - IGP office building, Gulbarga, Karnataka.

The Karnataka State Police Housing Corporation constructed a new office complex for the Inspector General of Police Office (IGP) in the city of Gulbarga. The IGP complex is the first "green building" in the government sector in the country. This building is a ground and two-story structure designed by the Kembhavi Architecture Foundation to house the offices of the Inspector General of Police, Gulbarga with a built-in area of 30,000 sq ft. The building is constructed using innovative materials. The building has won the international LEED (Leadership in Energy and Environmental Design) gold rating. For example, the external walls are composite walls (i.e., granite blocks on the outer side and rat-trap bond brick walls on the inner side) and the roof is made of filler slab. The U-values of the walls and roof are 1.53 W/m^2-K and 2.15 W/m^2-K respectively. The building is roughly rectangular with a longer axis along the North-South direction. Most windows face East or West. The passive architecture of this building incorporates an evaporative cooling technique. This building uses solar energy which is used for street lighting and water pumping. The building has installed solar-powered water pumps for pumping continuous water required for the operation of wind towers. Rat trap type of brick masonry insulates the building against heat from solar radiation. Terrace green grass and china mosaic over covered vaults also help to reduce the effects of heat radiation. As the building is located in a hot and dry climate, evaporative cooling has been used for providing comfort. Most of the offices are cooled by a passive downdraft evaporative cooling tower system. The energy-saving comes to about 23% and the water saving is 47%. The project cost is around 32.20 million.

6.2.2.1 Energy conscious features

The various measures adopted in the building to achieve energy efficiency are as follows.

- Tinted glasses to reduce glare.
- Alternative building materials such as composite walls reduce heat gain.
- Filler slabs to reduce the quantity of concrete in the structure.
- A central atrium to enhance cross ventilation and provide day-lighting.
- Composite walls and filler slabs have been used instead of concrete to reduce heat gain.
- PDEC (Passive Downdraft Evaporative Cooling) towers for providing comfort.
- Projected canopy around the building of 90 cm and the Trombe walls of 60 cm along both sides of the windows were used to minimize the sunrays entering the buildings.
- Solar energy for lighting and water pumps, rainwater harvesting, and water recycling facilities for PDEC towers.

The IGP office complex at Gulbarga perfectly uses landscapes, recycled building materials, renewable energy sources, and water management. The architecture of this building incorporates an evaporative cooling procedure. This building uses solar energy which is used for street lighting and water pumping. The building has installed solar-powered water pumps for pumping water required for wind towers. Rat trap type of brick stone work insulates the building against heat from solar radiation. Porch green grass and china mosaic over covered vaults additionally aides to reduce the effects of heat radiation. All of these result in a reduction in energy usage and thereby result in energy cost savings.

6.2.2.2 Root zone treatment

The sewage treatment system in the IGP office building in Gulbarga consists of sand, gravel, and soil material. Specific species of plants reduce the complex biological waste into elemental nutrients. The length is designed to maintain the minimum retention period and the breadth is designed for optimum effluent flow rate. This root zone treatment reduces Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of grey water below the maximum levels. The treated water is used for gardening.

6.2.2.3 Renewable energy

The IGP Office complex, Gulbarga meets 20% of its electricity needs through solar photo voltaic panels. Solar electric power is used to lift water for domestic use and re-circulate water in the wind towers. Vestas has installed wind turbines of 950 kW off-site to meet 100% energy requirements of the building.

6.2.2.4 Wind towers

The IGP office complex in Gulbarga does not use mechanical air conditioning systems for cooling instead, they use wind towers. The complex has ten wind towers and the temperature inside the complex reduces by ten degrees.

6.2.3 Case study 3 - Suzlon One Earth, Pune, Maharashtra, India

The Suzlon One Earth campus is a unique corporate headquarters spread over ten acres of land in Hadapsar, Pune, India. The place was conceived with a business and functional need to bring all business verticals and corporate services under one roof, which although linked to each other would be independent enough to be able to perform as per their respective needs and requirements. The Suzlon Group is one of the world's leading wind turbine manufacturers providing wind energy solutions. The journey of powering a greener tomorrow began for Suzlon in 1995. Apart from being a technology leader, Suzlon prides itself in championing the cause of sustainable energy thus creating a lasting and harmonious environment. Suzlon's philosophy is to pursue social, economic, and ecological sustainable development of the planet. Suzlon believes that the only way to predict the future is to help shape it.

6.2.3.1 Description

- Location: Hadapsar, Pune
- Site: 45392m^2.
- Built-up Area: 70865m^2.
- Air-conditioned area: 40418m^2.
- Non-air-conditioned area: 24582m^2.
- Energy consumption reduction: 47% reduction from GRIHA benchmark.
- Water consumption reduction: 65% reduction from GRIHA benchmark.
- Environmental Performance Index (EPI): 55.86 kWh/m^2/Year.
- Occupancy hours: 2640 hrs/year.
- Renewable energy installed on site: 154.83 kW.
- GRIHA rating: 5 star (96 points).
- LEED rating: Platinum (57 points)

Suzlon Group is among the world's leading renewable energy solutions providers that are revolutionizing and redefining the way sustainable energy sources are harnessed across the globe. At present, in 18 countries across Asia, Australia, Europe, Africa, and the Americas, Suzlon is powering a greener tomorrow with its strong competency in renewable energy systems. Sustainable development is the creed that highlights Suzlon's bespoke initiatives to protect the environment, strengthen communities and propel responsible growth. Suzlon is Headquarters in located at One Earth - Pune, which is a Platinum LEED (Leadership in Energy and Environment Design) certified and GRIHA 5 star rated campus and is also among the greenest corporate campuses in the world.

6.2.3.2 Sustainable features

Living the company's motto, "powering a greener tomorrow", the architect relied exclusively on non-toxic and recycled materials. A million square feet of ground plus two levels in a 10.4 - acre urban setting achieved a LEED Platinum and GRIHA 5 Star certification with 8% of its annual energy generated on-site through photovoltaic panels and windmills with a total incremental cost of about 11%. There are no other LEED-certified buildings with this level of certification and on-site renewable energy that have achieved this kind of cost - efficiency. 154 kW of electricity is produced on-site (80% wind and 20% photovoltaic). All other energy (4MW) is produced in the client's wind mill farms. With 92% (4 MW) being consumed by the project is 'sustainable energy' making this a Zero Energy building.

- Sustainable site planning:
    - Dust screens were provided around the construction area to prevent air pollution.
    - Soil erosion control measures were adopted on-site.
    - Utility corridors were designed along roads and pathways on site.
- Reduction in water consumption (Compared to GRIHA benchmark):
    - By using low–flow fixtures there is a reduction in building water consumption by 65% reductions.
    - 55% of water is recycled and reused within the complex.
    - By planting native species of trees and shrubs and by using efficient irrigation systems, landscape water consumption has been reduced by 55%.

- Passive architectural design strategies adopted in the building:
    - ➢ Orientation of the building is such that the facades of the building face north, south, northwest, and southeast.
    - ➢ The external louvers provide a hundred percent shading on the first and the second floors.
    - ➢ Partly self–shading blocks are also used.
    - ➢ Small terraces have been created in all blocks to promote interaction with the externals environment.
- Reduction in energy consumption (compared to GRIHA benchmark) while maintaining occupant comfort:
    - ➢ For achieving visual comfort adequate day lighting and glare control measures have been adopted and all the works desks are equipped with LED lights governed by motion sensors.
    - ➢ Pre-cooling of fresh air used to achieve thermal comfort and heat recovery or exchange mechanisms is installed to minimize energy consumption.
    - ➢ Highly efficient mechanical systems have been used to reduce energy consumption.
- The usage of low - energy or green materials:
    - ➢ 37% reduction in the quantity of structural concrete by using post-tension slabs
    - ➢ 50% reduction in the quantity of structural steel by using post-tension slabs.
    - ➢ Use of siporex fly ash block for better insulation.
- In the Wind Lounge, there is a very traditional Indian Chowk here, with kund-like steps leading into a water pool shaded by photovoltaic panels allowing filtered light in, as if through an ancient jaali.
- Aluminium louvers act as protective skin allowing daylight and cross ventilation. All areas have operable fenestration allowing natural air and ventilation whenever possible. These strategies resulted in lower, thinner, and longer building shapes

that increase the ratio of fenestration to volume, enhancing natural light and ventilation in hot and dry climatic conditions.

- The Deepa Stambh is set in the center of the Suzlon reflecting pool. The pool rests at the basement level, wherein all of the cafeteria and the dining room open onto the water. In the background, this is seen as a cascade of waterfalls, flying down three levels of tiers, with traditional step-like objects giving rhythm to the backdrop. A long water basin feeds the water falling through a pumping system. The lineal basin links the Brahmasthal to a fountain toward the east. These auspicious components protect the campus from unwanted influences and create a central focus and landmark. They bring very Indian features within a global and high-tech ambiance. A large water body in the central court helps to improve the air quality and evaporative cooling. All the external landscape areas are brought indoors along the perimeter of the building, bringing fresh air, nature, and natural light into the work areas to improve occupants' productivity. This central garden plaza encourages communication, interaction, and innovation among the 2300 colleagues and provides a stunning aesthetic presentation for visitors.
- The building employs complex building management systems. Lighting of individual offices is controlled by combined daylight and occupancy sensors. 65% of energy is saved by the usage of LED outdoor light systems in comparison to conventional scheme. 30 - 40% reduction in operating cost, due to energy savings and water savings at 30%.

Suzlon One Earth is an 816,000 SF Commercial building. It is three levels high and is built on 10.5 acres. It achieved LEED for New Construction Platinum certification from the India Green Building Council, as well as Five-star GRIHA (Green Rating for Integrated Habitat Assessment) certification. Five percent (154 kW) of its annual energy is generated on-site through conventional and building-integrated photovoltaic panels (20%) and wind turbines (20%). All balance energy required for the campus is generated through Suzlon's off-site wind turbines, making one earth technically a zero-energy project. The design provides 90% of the workstation with daylight and external views. Aluminium louvers act as protective skin, allowing daylight and cross-ventilation. Energy is saved by employing LED lighting systems and solar water heating. 100% of sewage grey water is recycled into flushing, landscaping, and air-cooling systems, while 100% of rainwater is harvested. Glass exhaust chimneys with tropical plants act as visual connectors between all floors and allow aeration of the basement parking area. The project site was selected for the advantages of an already developed area. It is flanked by offices of other corporations and a high-density residential area. Given its location, the building has access to urban infrastructure and facilities, public transport, and established infrastructure for power and water supply.

6.3 ASSESSMENT DETAILS OF CASE STUDIES

The sustainable indicators are evaluated for three cases. For economical assessment, the LCC method is used to quantify cost at every stage in building life cycle. The subjective indicators that consist of sustainable site and heritage conservation included for environmental assessment are qualified using the value score approach by surveying the design team in the cases. For the objective indicators such as energy consumption, GHG emission included for environmental assessment is quantified using the LCA approach with inventory analysis. The social assessment indicators are qualified using the VS approach.

6.3.1 Environmental assessment

i) The LCA approach for quantitative indicators

The criteria of indicators discussed in Chapter 5 are used for quantitative measurement. The LCA Method is applied for objective indicators like energy consumption, GHG emission, and material consumption. There are three types of data collected for LCA approach:

- Project details which included the quantity of materials utilized and material consumption are based on this. The constituents of the construction materials used are calculated based on their composition.
- Equipment information includes the type, running – time, and amount of equipment. Average electricity consumption data is collected for electrical equipment. Energy consumption on site is calculated using this information.
- Ancillary material data that gives information regarding materials used for replacement and repairs.

ii) The VS approach for qualitative indicators

The VS approach is used for qualitative indicators. For the assessment, an expert panel is selected for the survey. Experts associated closely with the green building projects were selected and were contacted through email and invited to join the scoring process. The professional background and knowledge of the experts in green building assessment were considered to decide the panel for the assessment of the three cases. A panel of six experts was selected for each case. The experts selected had work experience of 10years and above and some of them are members of Leadership in Energy and Environmental Design (LEED) certified and Indian Green Building Council Accredited Professionals (IGBC AP). Further information regarding the expert panel is provided in Table 6.2. A questionnaire was prepared and sent to the experts through email. The questionnaire contained the qualitative indicators along with their criteria (refer to Appendix II). The experts were asked to value the score for the qualitative indicators from -2 to +5, including environmental and social indicators (Refer to Table 5.1).

Table 6.2: Expert Panel for Survey

Interviewee	Job Title	Area of Specialization	Experience in years
A	Green Building Engineer	Green Building Consultant	10
B	Architect / Green Building Consultant	Eco-friendly Construction	35
C	Architect	Green Building	32
D	Developer / Contractor	Low Energy Building	34
E	Architect / Consultant	Green Building	38
F	Consultant	Green Building Materials	15

The final score for every indicator is obtained by considering the average of all the scores obtained from each expert for that indicator. Value score represents results of qualitative indicators whereas quantities of those indicators are calculated in their own unit and this is tabulated in Table 6.3.

Table 6.3: Environmental assessment details for three case studies

Building Division	Indicators	Unit	Case study 1	Case study 2	Case study 3
GFA (m^2)			**31400**	**2817**	**70865**
Inception and Design stage	Sustainable site	-	4.1	3.9	4.2
	Sustainable material	-	4.6	4.6	4.7
	Sustainable design	-	4.4	4.6	4.7
	Heritage conservation	-	3.5	3.5	3.4
	Topography and climatic conditions	-	4.4	3.3	4.4
Construction stage	Energy	MJ/m^2	43.75	123.02	55.86
	Water	Kg/ m^2	6.62	10.28	4
	Resource	Kg/ m^2	1062.80	1506.82	1063
	Waste	Kg/ m^2	28.56	10.5	42.9
	Noise	dB	75	85	70
	Emission	$KgCO_2/m^2$	400.65	296.54	380
Operation stage	Energy	MJ/m^2	501.68	1411.01	300.05
	Water	Kg/ m^2	95.911	117.88	35.11
	Resource	Kg/ m^2	100.26	134.178	40.62
	Emission	Kg/ m^2	3390.7	3646.61	890.79
	Domestic and solid waste	Kg/m^2	357.51	491.95	150.15
Demolition stage	Waste	Kg/m^2	865.80	1296.82	500.30
	Noise	dB	70	85	75
	Emission	$KgCO_2/m^2$	11.26	13.45	30.16

6.3.2 Economic assessment – LCC approach

As discussed, LCC approach is used for economic assessment in all the cases. The capital costs of the projects are reliable for their project budgets. The project's operating cost includes salary, energy bill, water bill, security cost, and cost incurred for repair and replacement. Energy and water bill are calculated based on unit price and consumption.

The type, running – time and amount of equipment, and average electricity consumption by the equipment are used to calculate each case's electricity consumption. Daily water usage for the office building is used to calculate the water consumption. Salary is calculated by personal composition for different positions and the average salary is estimated. Security cost comprises of salary for the security in charge and security equipment. The price list from the local cleaning company is to calculate the cleaning cost. The demolition cost is calculated based on the Analysis of rates for Construction Project, Central PWD, 2014, 2nd volume.

From Table 6.4, the three cases have different economic characteristics. Land cost of the three buildings is different because they are situated in different locations. No exact comparison can be made since they are located in different cities in India and are constructed at different times and these cost figures are just for reference purposes. Construction cost for Case 1 is found to be higher than Case 2 and Case 3; this can be because of the green materials and techniques used for the construction. These green materials and techniques in construction have advantages in the later stages.

Table 6.4: Economical assessment details for three case studies

Building Division	Indicators	Unit	Case study 1	Case study 2	Case study 3
GFA (m^2)			**31400**	**2817**	**70865**
Inception and design stage	Land cost	Rs /m^2	23220	4247	5927
	Project Management Consultancy charges	Rs /m^2	350	350	158
	Other costs and charges	Rs /m^2	200	100	90
Construction stage	Construction cost	Rs /m^2	3462.53	1480.61	1580
	Project Management Consultancy charges	Rs /m^2	640	550	3952
	Other costs and charges	Rs /m^2	119	55.61	64.68
Operation stage (50 years)	Operating cost	Rs /m^2	51260.19	56847.53	30028
	Maintenance cost	Rs /m^2	1500	2000.06	3952
	Occupancy cost	Rs /m^2	550	250	420
Demolition stage	Demolition cost	Rs /m^2	1650	2500	3552
	Salvage value	Rs /m^2	2400	1275	3000
	Other costs and charges	Rs /m^2	85	105	70

6.3.3 Social assessment – The VS approach

VS approach was used for social assessment. Professionals closely associated with the project were considered for the questionnaire survey. The survey was conducted along with the qualitative environmental indicators as discussed in the previous chapter. From Table 6.5, Case study 2 has the lowest score in all indicators than Case study 1 and Case study 3 in the inception and design stage and the construction stage as well. In the operation stage, Case study 2 has the lowest score in stakeholders' relations, security measures, and risk management measures whereas Case study 1 has the lowest score in occupants' health and comfort, and Case study 2 and Case study 3 have the same score in occupants' satisfaction and productivity. In the demolition stage, Case study 2 has the lowest score in impact on the community but in the case of health and safety indicators and Case study 3 has the lowest score.

Table 6.5: Social assessment details for three case studies

Building Division	Indicators	Case study 1	Case study 2	Case study 3
Inception and design stage	Impact on community	4.7	4.2	4.4
	Urban integration	4.3	3.8	4.6
	Accessibility to public transport and other facilities	4.2	3.5	4.4
	Cultural issues	3.4	2.4	3.7
Construction stage	Impact on community	4.2	3.8	4.1
	Construction workers health, safety and hygiene	4.2	3.5	3.9
	Construction risk management	4.4	3.8	4.2
Operation stage	Occupants health and comfort	3.9	4.2	4.3
	Stakeholder's relation	4.1	4	4.1
	Occupants satisfaction and productivity	4.3	4	4
	Security measures	4	3.1	3.9
	Risk management measures	4	3.6	4.1
Demolition stage	Impact on community	3.7	3.5	3.6
	Health and safety	4	3.9	3.8

6.4 WEIGHING SYSTEM IN BPS MODEL

AHP matrix is used to calculate the weightage for each indicator after they are evaluated. Standardization of scores is essential as the indicators are quantified and qualified in different units and combining them in the BPS model. BPS score is calculated based on the weightage summation for each case. BPS results in the case studies are compared and their performance in each stage is also compared.

6.4.1 AHP method

As discussed, in order to calculate weightage for the indicators, the AHP method is used. To gather data and information for pair–wise comparison, the panel of experts was recruited. A panel of six experts from various fields in construction industry having thorough knowledge about sustainability was selected for the study. The experts selected had work experience of 10 years and above and some of them are members of Leadership in Energy and Environmental Design (LEED) certified and Indian Green Building Council Accredited Professionals (IGBC AP). The details of the case studies were provided to the panel to value the indicators in the AHP analysis. The same panel was considered for the value score process in the case of both the projects. A questionnaire was prepared for AHP analysis and the same can be found in Appendix III.

The questions were designed in the following manner to get pair - wise comparison:

- 1 Equal importance
- 3 Moderate importance
- 5 Strong importance
- 7 Very strong or demonstrated importance
- 9 Extreme importance
- 2,4,6,8 Intermediate values

Five indicators were identified in the environmental aspect in inception and design stage. 10 questions were asked in the panel in order to get the lower left-hand matrix. From this, the matrix in inception and design for environmental aspect is shown below:

$$A_1 = \begin{vmatrix} 1 & 1/3 & 1/5 & 1/4 & 1/6 \\ 3 & 1 & 1/7 & 1/3 & 1/3 \\ 5 & 7 & 1 & 1 & 1/1 \\ 4 & 3 & 1 & 1 & 1/3 \\ 6 & 3 & 1 & 3 & 1 \end{vmatrix}$$

From the above matrix, maximum Eigen value is calculated which is 5.35

After λ_{max} is calculated, consistency test is carried out in order to check whether the results are acceptable or not for the assessment as per Eq. 5.3 and Eq. 5.4.

$$\text{Consistency index C.I.} = \frac{\lambda max - n}{n-1} = \frac{5.35-5}{5-1} = 0.089$$

$$\text{Consistency ratio C.R.} = \frac{C.I.}{R.I} = \frac{0.089}{1.12} = 0.08 < 0.1$$

The results are acceptable as C.R. < 0.1 (Vyas et al. 2019a)

Similarly, the remaining matrix is formed in order to calculate the weightage for indicators based on the results obtained from the survey. The weightage obtained by the indicators in inception and design stage is tabulated in Table 6.6.

Table 6.6: Weighting for environmental indicators in inception and design stage

A/B	Sustainable site	Sustainable material	Sustainable design	Heritage conservation	Topography and climatic condition	**Weightage**
Sustainable site	1	0.33	0.2	0.25	0.17	**0.05**
Sustainable material	3	1	0.14	0.33	0.33	**0.09**
Sustainable design	5	7	1	1	1	**0.32**
Heritage conservation	4	3	1	1	0.33	**0.20**
Topography and climatic condition	6	3	1	3	1	**0.34**

Similarly, weightage for other indicators is calculated at every stage. The weighting for each indicator obtained from AHP analysis is tabulated in Table 6.7. The weightings obtained from the analysis for each indicator are applied in the model to generate scores. Sustainability score in each case for the building was calculated by weightage summation. Multiplying each value by its applicable weight, the score is calculated and then followed by the summation of weighted scores for all indicators.

Table 6.7: AHP weighting for indicators in pillars and building division

Building Division	Pillars	Indicators	Weightings
Inception and Design Stage	Environmental	Sustainable site	0.05
		Sustainable material	0.09
		Sustainable design	0.32
		Heritage conservation	0.2
		Topography and climatic condition	0.34
	Economical	Land cost	0.13
		Project management consultancy charges	0.12
		Other costs & charges	0.75
	Social	Impact on community	0.1
		Urban integration	0.29
		Accessibility to public transport and other facilities	0.34
		Cultural issue	0.27
Construction Stage	Environmental	Energy	0.14
		Water	0.14
		Resources	0.14
		Waste	0.17
		Noise	0.22
		Emissions	0.19
	Economic	Construction cost	0.15
		Project management consultancy charges	0.13
		Other costs and charges	0.72
	Social	Impact on community	0.12
		Construction workers health and safety	0.41
		Construction risk management	0.47
Operation Stage	Environmental	Energy	0.12
		Water	0.08
		Resources	0.14
		Emissions	0.14
		Domestic and solid waste management	0.51
	Economical	Operation cost	0.26
		Maintenance cost	0.41
		Occupancy cost	0.33
	Social	Occupants health and safety	0.19
		Stakeholder relations	0.16
		Occupier satisfaction and productivity	0.25
		Security measures	0.19
		Risk management measures	0.19
Demolition Stage	Environmental	Waste	0.19
		Noise	0.17
		Emissions	0.63
	Economical	Demolition cost	0.26
		Salvage value	0.41
		Other costs and charges	0.33
	Social	Impact on community	0.25
		Health and safety	0.75

6.4.2 Model calculation

The indicators considered for the assessment are measured in different methods and units. Value score approach is used for qualitative environmental and social indicators whereas quantitative indicators in environmental and economic aspects are measured in their own units. Therefore, there is a need for standardization to a common unit that is dimensionless and is to be done before weighted summation is applied.Interval standardization is used in the research as mentioned earlier. The qualitative environmental and social indicators (higher the better) gain a positive sign whereas qualitative environmental and economic indicators (lower the better) gain a negative sign before standardization. As a result, a high score signifies a low burden on the environment, low cost, and high social benefits. Results after standardization for every stage in case studies are tabulated in Table 6.8, Table 6.9, Table 6.10, and Table 6.11.

Table 6.8: Building performance score in the inception and design stage of the three case studies

PILLARS	INDICATORS	CASE STUDY 1			CASE STUDY 2			CASE STUDY 3			
		Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Weightage
Environmental	Sustainable site	4.1	0.67	0.03	3.9	0	0	4.2	1	0.05	0.05
	Sustainable material	4.6	0	0	4.6	0	0	4.7	1	0.09	0.09
	Sustainable design	4.4	0	0	4.6	0.67	0.21	4.7	1	0.32	0.32
	Heritage conservation	3.5	1	0.2	3.5	1	0.2	3.4	0	0	0.2
	Topography and climatic condition	4.4	1	0.34	3.3	0	0	4.4	1	0.34	0.34
				0.57			**0.41**			**0.8**	
Economic	Land cost	23220	0	0	4247	1	0.13	5927	0.91	0.12	0.13
	Project management consultancy charges	350	0	0	350	0	0	158	1	0.12	0.12
	Other costs & charges	200	0	0	100	0.91	0.68	90	1	0.75	0.75
				0			**0.81**			**0.99**	
Social	Impact on community	4.7	1	0.1	4.2	0	0	4.4	0.4	0.04	0.1
	Urban integration	4.3	0.63	0.18	3.8	0	0	4.6	1	0.29	0.29
	Accessibility to public transport and other facilities	4.2	0.78	0.26	3.5	0	0	4.4	1	0.34	0.34
	Cultural Issue	3.4	0.77	0.21	2.4	0	0	3.7	1	0.27	0.27
				0.75			**0**			**0.94**	
BPS (I)				**1.32**			**1.22**			**2.73**	

Building Performance Score in each pillar (orange)
Building Performance Score in each stage (green)

Calculation of standardization is based on Equation 5.5 where 1 and 0 signify best and worst outcomes respectively. Considering the indicator "sustainable site" in inception and design stage has value score for the three cases as 4.1, 3.9, and 4.2. The standardization in Case study 1 is calculated as follows:

$$\mathbf{S = \frac{4.1-3.9}{4.2-3.9} = 0.67}$$

After the calculation, BPS_I for Case study 1 is 1.32, for Case study 2 is 1.22 and for Case study 3 is 2.73. These figures signify that Case study 3 has better performance in this stage followed by Case study 1 and Case study 2 is found to have the worst performance in this stage.

Table 6.9: Building performance score in construction stage of the three case studies

PILLARS	INDICATORS	CASE STUDY 1			CASE STUDY 2			CASE STUDY 3			
		Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Weightage
Environmental	Energy	43.75	1	0.14	123.02	0	0	55.86	0.85	0.12	0.14
	Water	6.62	0.58	0.08	10.28	0	0	4	1	0.14	0.14
	Resources	1062.8	1	0.14	1506.82	0	0	1063	0	0	0.14
	Waste	28.56	0.44	0.08	10.5	1	0.17	42.9	0	0	0.17
	Noise	75	0.67	0.15	85	0	0	70	1	0.22	0.22
	Emissions	400.65	0	0	296.54	1	0.19	380	0.19	0.04	0.19
				0.59			**0.36**			**0.52**	
Economical	Construction cost	3462.53	0	0	1480.61	1	0.15	1580	0.95	0.14	0.15
	Project management consultancy charges	640	0.97	0.13	550	1	0.13	3952	0	0	0.13
	Other costs & charges	119	0	0	55.61	1	0.72	64.68	0.86	0.62	0.72
				0.13			**1**			**0.76**	
Social	Impact on community	4.2	1	0.12	3.8	0	0	4.1	0.75	0.09	0.12
	Construction workers health and safety	4.2	1	0.41	3.5	0	0	3.9	0.57	0.23	0.41
	Construction risk management	4.4	1	0.47	3.8	0	0	4.2	0.67	0.31	0.47
				1			**0**			**0.63**	
BPS (C)				**1.72**			**1.36**			**1.91**	

BPS_C for Case study 1, Case study 2, and Case study 3 are 1.72, 1.36, and 1.91 respectively. These figures signify that Case 3 has better sustainability performance than Case study 1 and Case study 2 in the construction stage. Construction processes have a notable impact on environmental and social aspects. When all the three pillars of sustainability are considered individually, the results obtained are different. Case study 2 has the lowest score when compared to the other two cases in environmental and social aspects in this stage but has the highest score in economical aspects. Case study 2 is found to have the worst performance in this stage and the probable reason for this might be its location. Case study 1 has the lowest score in the economic aspect and the probable reason for this might be that some sustainable and green technology costs more in construction.

Table 6.10: Building performance score in operation stage of the three case studies

PILLARS	INDICATORS	CASE STUDY 1			CASE STUDY 2			CASE STUDY 3			
		Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Weightage
Environmental	Energy	501.68	0.82	0.09	1411.01	0	0	300.05	1	0.12	0.12
	Water	95.911	0.27	0.02	117.88	0	0	35.11	1	0.08	0.08
	Resources	100.26	0.36	0.05	134.178	0	0	40.62	1	0.14	0.14
	Emissions	3390.7	0.09	0.01	3646.61	0	0	890.79	1	0.14	0.14
	Demolition & solid waste management	357.51	0.39	0.2	491.95	0	0	150.15	1	0.51	0.51
				0.37			**0**			**0.99**	
Economic	Operation cost	51260.19	0.21	0.05	56847.53	0	0	30028	1	0.26	0.26
	Maintenance cost	1500	1	0.41	2000.06	0.79	0.33	3952	0	0	0.41
	Occupancy cost	550	0	0	250	1	0.33	420	0.43	0.14	0.33
				0.46			**0.66**			**0.40**	
Social	Occupants health & safety	3.9	0	0	4.2	0.75	0.14	4.3	1	0.19	0.19
	Stakeholders relations	4.1	1	0.16	4	0	0	4.1	1	0.16	0.16
	Occupier satisfaction and productivity	4.3	1	0.25	4	0	0	4	0	0	0.25
	Security measures	4	1	0.19	3.1	0	0	3.9	0.89	0.17	0.19
	Risk management measures	4	0.8	0.15	3.6	0	0	4.1	1	0.19	0.19
				0.75			**0.14**			**0.71**	
BPS (O)				**1.58**			**0.8**			**2.1**	

BPS_O for Case study 1, Case study 2, and Case study 3 are 1.58, 0.8, and 2.1 respectively. These figures signify that Case study 3 has better sustainability performance than the other two cases in operation stage. Case study 2 has better economic performance compared to the other two cases but has the lowest score in the environmental and social aspects. The possible reason for this is that it maintains the economic factors but fails to address the environmental and social aspects during this stage. Case study 3 has better environmental performance than the other two cases and the probable reason for this might be that the project had incorporated sustainable and green technology to improve the performance during the operation stage of the building. Case study 1 has better performance in social aspects compared to the other two cases as it incorporates measures essential to attain good social performance.

Table 6.11: Building performance score in demolition stage of the three case studies

PILLARS	INDICATORS	CASE STUDY 1			CASE STUDY 2			CASE STUDY 3			
		Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Quantities (GFA) /Score	Standardization	Score	Weightage
Environmental	Waste	865.8	0.54	0.10	1296.82	0	0	500.3	1	0.19	0.19
	Noise	70	1	0.17	85	0	0	75	0.67	0.11	0.17
	Emissions	11.26	1	0.63	13.45	0.88	0.56	30.16	0	0	0.63
				0.9			**0.56**			**0.3**	
Economic	Demolition cost	1650	1	0.26	2500	0.55	0.14	3552	0	0	0.26
	Salvage value	2400	0.65	0.27	1275	0	0	3000	1	0.41	0.41
	Other costs & charges	85	0.57	0.19	105	0	0	70	1	0.33	0.33
				0.72			**0.14**			**0.74**	
Social	Impact on community	3.7	1	0.25	3.5	0	0	3.6	0.5	0.13	0.25
	Health and safety	4	1	0.75	3.9	0.5	0.38	3.8	0	0	0.75
				1			**0.38**			**0.13**	
BPS (D)				**2.62**			**1.08**			**1.17**	

BPS_D for Case study 1, Case study 2, and Case study 3 is 2.62, 1.08, and 1.17 respectively. These figures signify that Case study1 has better sustainability performance than Case study 3 followed by Case study 2 in the demolition stage. When the three pillars are considered, Case study1 has better environmental and social performance than Case study 2 followed by Case study 3 whereas Case study 3 has better economic performance than Case study 1 followed by Case study 2. One of the probable reasons for the poor social performance of Case study 3 might be that they fail to consider the social aspects, especially the health and safety of workers during the demolition stage.

Table 6.12: Summary of building performance scores for the three case studies

Stages	CASE STUDY 1				CASE STUDY 2				CASE STUDY 3			
	Env	**Eco**	**Soc**	**Total**	**Env**	**Eco**	**Soc**	**Total**	**Env**	**Eco**	**Soc**	**Total**
Inception and design stage	0.57	0.00	0.75	1.32	0.41	0.81	0.00	1.22	0.80	0.99	0.94	2.73
Construction Stage	0.59	0.13	1	1.72	0.36	1.00	0.00	1.36	0.52	0.76	0.63	1.91
Operation Stage	0.37	0.46	0.75	1.58	0.00	0.66	0.14	0.80	0.99	0.40	0.71	2.10
Demolition Stage	0.90	0.72	1	2.62	0.56	0.14	0.38	1.08	0.30	0.74	0.13	1.17
Total				**7.24**				**4.47**				**7.92**

Note: Env-Environmental, Eco-Economic, Soc-Social

Building Performance Score (BPS) for the three cases is tabulated in Table 6.12 which also shows the performance at every stage of the building in its complete life cycle. This signifies the benefits and shortcomings of each case in three pillars at every stage. For instance, Case study 3 has much better performance in the economic aspect than the other two cases in the inception and design stage. Case study1, as a green building, may spend much more than the other in the inception and design stage, thus it gets the lowest economic score in this stage. The total score of the different stages of the three case studies is shown below.

Case study 1	**7.24**
Case study 2	**4.47**
Case study 3	**7.92**

The full score for BPS model is 12. It can be divided for four levels:

- 0 – 3 Indicates poor sustainability performance
- 3.1 – 6 Indicates moderate sustainability performance
- 6.1 – 9 Indicates good sustainability performance
- 9.1 - 12 Indicates excellent sustainability performance

Results from Table 6.12 illustrate that Case study 1 and Case study 3 have good sustainability performance and Case study 2 has moderate sustainable performance as shown in Figure 6.1.

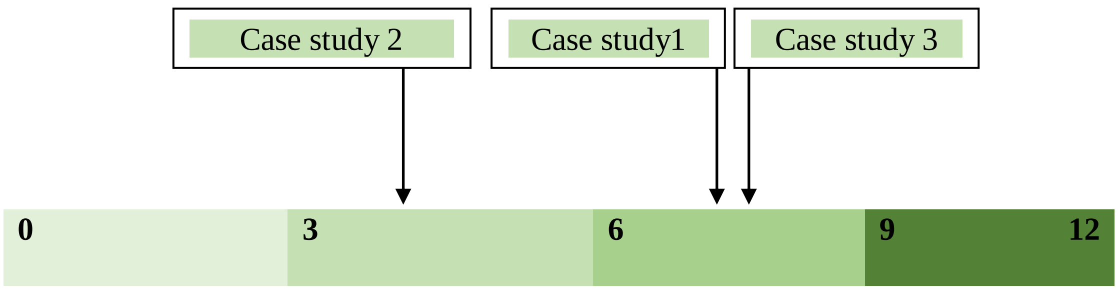

Figure 6.1: BPS for the three case studies

The benefit of BPS is that it shows the performance of a building at every stage in its life cycle and comparison of the three cases in each pillar and stage. In the inception and design stage, Case study 3 has the best sustainability performance in all the three pillars than the other two cases. In the construction stage, Case study 1 has better sustainability performance in environmental and social aspects; Case study 2 has better sustainability performance in economical aspects. In the operation stage, Case study 3 has better sustainability performance in environmental aspects; Case study 2 has better sustainability performance in economic aspects and Case study 1 has sustainability performance in social aspects. In the demolition stage, Case study 1 has better sustainability performance in environmental and social aspects and Case study 3 has better sustainability performance in economic aspects.

A comparison of sustainability performance of the three cases at every stage of the building is as follows:

- The sustainability performance of the three cases in inception and design stage is Case study 2 < Case study 1 < Case study 3.

- The sustainability performance of both the cases in construction stage is Case study 2 < Case study 1 < Case study 3.
- The sustainability performance of both the cases in operation stage is Case study 2 < Case study 1 < Case study 3.
- The sustainability performance of both the cases in demolition stage is Case study 2 < Case study 3 < Case study 1.

Essential redesigning and other actions can be taken before the beginning of actual construction as the performance assessment is done at every stage. For instance, Case study 3 has the worst score in the environmental aspect in the demolition stage refer to Table 6.11. To improve this situation, necessary actions such as increasing recycling and reusing of construction materials can be undertaken in the early stage. Case study 1 has a low score in the economic aspect in the construction stage refer to Table 6.9. This signifies that the project has high construction costs and some actions are necessary at the early stage to decrease the construction cost by considering design, structure, and materials selection. Also, being different from other sustainable assessment tools, this shows the impact on the environment at every stage as the actual amount of these indicators are calculated.

6.5 BPS RESULTS COMPARISON WITH LEED – INDIA RATINGS

To have a more precise objective evaluation of BPS, a comparative study has been done by considering one of the popular tools called LEED ratings.

6.5.1 Assessment of projects by adopting LEED

There are six major categories based on which LEED evaluates any project for its sustainability and they are sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and innovation and design. The LEED ratings and scores for the three cases studies for each criterion are represented in Table 6.13. Case study 1 has gained 53 in total and is qualified as platinum; Case study 2 has gained 41 in total and is qualified as gold; Case study 3 has gained 57 in total and is qualified as platinum.

Table 6.13: Summary of LEED points and ratings for the three case studies

Sl No.	Criteria	Max. Available	Case study 1	Case study 2	Case study 3
1	**Sustainable Sites**	13	11	09	10
2	**Water Efficiency**	06	05	05	06
3	**Energy and Atmosphere**	17	15	08	14
4	**Materials and Resources**	13	04	05	07
5	**Indoor Environmental Quality**	15	13	10	15
6	**Innovation and Design**	5	05	04	05
	TOTAL	**69**	**53**	**41**	**57**
	RATING		**Platinum**	**Gold**	**Platinum**

From Table 6.13, it can be found that Case study 1 gains more points than the other two cases in criteria for sustainable sites. Development density and community connectivity are the two essential issues for a developed area and these are the required indicators. The three cases are found to have gained almost the same score in water efficiency criteria. This criterion comprises three credits, water efficiency, modern wastewater technologies, and reducing water usage. Case study 1 gained more points than the other two cases in the criteria energy and atmosphere. This criterion comprises six credits, on-site renewable energy, enhanced commissioning, enhanced refrigerant management, measurement and verification, and green power. Case study 3 gains more points than the other two cases in criteria materials and resources. This criterion comprises seven credits i.e. building reuse, construction waste management, materials reuse, recycled content, regional materials, rapidly renewable materials, and certified wood. Case study 3 gains more points than the other two cases in the criteria of indoor environmental quality. The three cases are found to have gained almost the same score in the criteria innovation and design.

In order to validate the model, the result obtained from the model is compared with LEED ratings. On comparing the overall LEED points, Case study 3 has better performance than Case study 1 followed by Case study 2. Here it is to be observed that Case study 1 and Case study 2 has obtained platinum rating and Case study 2 has obtained gold rating by LEED and it is evident that more importance is given to environmental aspects compared to economic and social aspects for the assessment. Whereas results from BPS showcase that considering the three aspects gives sustainable performance results. Case study 1 and Case study 3 have obtained platinum ratings by LEED by considering mainly the environmental aspects. Therefore, when all the three aspects are considered, these ratings might change because of the influence of economic and social aspects on the performance of the building. In case they have failed to address the economic and social aspects, they would acquire a lower rating than the present rating when all the three aspects are considered for the assessment. The same applies to project Case study 2 also. Hence it is important to incorporate environmental, economic, and social aspects for performance assessment as mentioned in the BPS model.

6.6 BENEFITS OF BPS

According to the discussion of the three case studies, the BPS model provides an opportunity to assess building performance in environmental, economical, and social aspects at every stage in the building life cycle. BPS model is different from other performance assessment models which only consider the environmental aspect whereas BPS considers the life cycle cost of the project and also its impact on local society. The advantage of this is that the stakeholders can understand better when they adopt this to assess the project. The concept of sustainability can be achieved by the building projects when all the three pillars are assessed.

BPS model considers all the stages in the building life cycle for the assessment. Assessing the sustainability performance at an early stage like the inception and design stage till the final stage (end-of-life stage) is done in this model. The case studies considered here also authenticate that the three criteria- environmental, economic, and social aspects have impacts at several stages of development. BPS model offers an approach different from other existing assessment tools for building assessment and provides a more comprehensive assessment process for building projects. Gaps of fuzzy and uncertainty in the checklist in the previous performance assessment tools are filled by the majorly quantified indicators. A more comprehensive result is obtained as there is a combination of both qualitative and quantitative indicators which also consider the opinions of the stakeholders'. Before the concept of the BPS model, the three pillars of sustainability and the life cycle of the building were just like a buzzword than an actual assessment process. Some of the assessment tools or models considered these two concepts. Results obtained from case studies justify that the BPS model can help in adding a more detailed vision to the building assessment process.

Performance assessment of the three case studies from life cycle perspective recommends some changes in order to improve the performance of the building. For instance, incorporating recycled and renewable materials for construction in the project Case study 2 can help in improving the environmental performance in both the inception and design stages. Similarly, incorporating green design in project Case study 3 can help in improving the economic performance in the operation stage. Therefore, including BPS in assessing the performance of a building at an early stage will help in improving the performance of the project from a life cycle perspective.

6.7 SUMMARY

Three case studies are presented in this chapter to validate the BPS model. Every stage of the building's life cycle is evaluated in terms of its environmental, economic, and social performance. The BPS model, which takes into account economic and social concerns, makes sustainability more reliable than previous building assessment tools or instruments. Furthermore, the building's performance at each step is evaluated so that stakeholders may select the plan that best meets their needs. The three case studies validate the model's practicability and viability. This study proposes a method for combining quantitative and qualitative markers in the evaluation process. In comparison to earlier SATs, the BPS takes a new approach to constructing assessment and provides more complete assessment findings.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

The currently used sustainable assessment tools were criticized in the literature review for not being efficient enough to include all the three pillars of sustainability in the building development phase. The construction industry in India requires a comprehensive model for sustainable performance of building at every phase of their development. To gather information and data, a questionnaire survey and semi-structured interviews were conducted. The survey intended to screen assessment indicators to develop a model and to study the actual situations of sustainable buildings and their assessment in India. The main aim of the sustainable assessment model is to assess the building performance considering the three pillars of sustainability, at the various development phases of the building. The model is developed based on the assessment indicators gathered from data collected and its analysis. Three green - certified projects were selected for the case study for model validation. The major findings from the research process are presented in this chapter.

7.2 SUMMARY OF RESEARCH

Research questions and problems are identified in Chapter 1. The currently used sustainable assessment tools were criticized for being not efficient enough to address the issues of sustainability regarding increased attention given to building performance. Moreover, the concept of life cycle assessment has not gained sufficient attention in India. Assessment tools are required to cover environmental, economic, and social impacts, as the main aim of sustainable construction is to balance all three aspects, not just the environmental aspect. A literature review suggests that all three components of project development differ at different phases of the development life cycle. Therefore, it is essential to include and assess the sustainability performance of the building from the initial stage to the end-of-life stage. This research aims to develop a model to assess building performance considering all three aspects, environmental, economic, and social, and carry out the assessment process throughout its complete life cycle.

7.3 REVIEWING AIMS AND OBJECTIVES OF THE STUDY

Currently used assessment tools are studied for their limitations in assessing the sustainability performance of the building. The research aims to formulate a model to evaluate the building performance considering the triple bottom line of sustainability. The assessment is done at every stage in the building life cycle.

7.3.1 Review details of building assessment tools and phases

The main objective of this study is to identify the gaps in present building assessment tools. Different assessment tools and models are discussed in Chapter 2, along with their applications in India. The majority of countries have their own assessment methods and models, and their development differs significantly. The tools for individual building components and the whole building can be very different. Most of the time, only the environmental aspect is considered and many builders ignore the stages in the life cycle of the building. Criticism arises because of the reason that assessment methods are essential to evaluate the performance of building in all three aspects, as this defines the term "building sustainability". Assessment methods are found to be more attractive in the construction industry when economic aspects are also taken into consideration.

Reviews of present assessment tools indicate that the impact on the building process throughout its life cycle requires attention to the assessment. Impacts of three sustainability aspects occur at different phases in the development cycle of a building and, hence, assessment at different stages becomes essential. Including sustainable principles in building construction can maximize the performance of sustainable aspects of development. The impact on design and construction practice enhances with assessment being carried out at different stages in the building development cycle. The shortfall faced by present assessment tools indicates that a more extensive assessment tool or model is required to assess the performance of building over its complete development cycle. Chapter 2 deals with stage divisions done in different ways, and it varies from 4 to 7 stages. These stage divisions, in different ways, consist of some divisions including construction activities and some divisions include activities only up to the operation stage. Discussions in Chapter 2 suggest that four or five divisions are acceptable in the construction industry for research purposes. The stage divisions selected by researchers comprise different building phases according to their own observation of the building industry practices.

This research aims at developing a model for sustainable assessment in the building life cycle and to do this, all the phases in the building development cycle are essential. Inception and design stages are combined as one stage as these have limited activities at briefing stages and have related sustainable impacts on the project life span. Furthermore, the construction and operation stages take place, and the demolition stage is the end-of-life stage. As a result, stage divisions are adopted in this study, which comprise of inception and design, construction, operation, and demolition stages. This division also satisfies the requirement to include all the activities from the beginning to the end of the project life cycle.

7.3.2 Review details of sustainability pillars concerned with building division

The other objective of the research based on the four stages of the building development cycle is to investigate the impacts of environmental, economic, and social aspects on the building. According to different stage divisions in the life cycle of a building, the three pillars are discussed in Chapter 2. Primarily, activities that are mainly associated with the different stage divisions are identified and then sustainability performance assessment associated with those activities in the building process is carried out. The physical work involved at the inception and design stage is very minimal and, therefore, it has a limited direct contribution towards the sustainability aspects. But it can still be assessed in building performance because of the fact that decisions made at this stage have an influence on further stages. This phase gives an excellent opportunity to bring all of the issues relating to sustainability performance together. Sustainability performance in environmental aspects can be best achieved at this stage through the selection of site location, technologies, and materials. Social aspects like local development and public services will also influence the project. The economic aspect is the least influential as there will be only a small part of capital input at this stage. Still, assessment of marketing costs, profit, and financing definitely has more significant influence on overall sustainability performance in the economic aspect.

There are a series of activities involved in the construction stage, such as the construction and installation of materials, and these activities are related to the high consumption of energy and the emission of GHG. The fuel used at construction sites for the equipment and for transportation, along with electricity used at construction sites for lighting and power tools is all included in this stage. Excessive consumption of materials and water, improper waste management, and generating pollutants at construction sites are contributors to environmental impacts. The social impact of this stage involves employment opportunities, and this stage is a vital component of the labor market. Occupants' health and safety, along with the impact on the neighborhood, are related to project construction. The economic aspect at this stage includes costs incurred for labor, materials, plants, and machinery, and this is considered the first priority by the stakeholders rather than environmental and social impacts in reality.

Need for occupants is fulfilled during the operation stage and activities like cooking, heating, lighting, ventilation, and water supply are included in this stage. Energy and resource consumption and emission of pollution are the major environmental impacts at this stage. During the life cycle of a building, these elements have the greatest impact on the environment. At this stage, the economic aspect includes expenses such as utility consumption, management staff hiring, and so on. The main concerns of social impact in the operation stage are the health, comfort, satisfaction, productivity, and relationships with stakeholders of the occupants. The demolition stage is the end-of-life stage in the building life cycle, which consists of processes associated with the recovery and utilizing the demolished building materials. It is considered to have some negative impact on the environment and also has a little positive contribution. Wastes obtained after the demolition of buildings and wastes disposed of in landfill forms are the major environmental impacts found at this stage. The demolition cost and the compensation was given create major impacts on the stakeholders from an economic aspect. The safety of the community becomes a social impact at this stage.

The building life cycle is divided into several phases, as discussed in Chapter 2 each of these phases has a vital role to play in building sustainability. Many researchers in previous studies have considered one or more phases, but not all the phases in the building life cycle. In the present study, all the phases of the building life cycle are taken into consideration and analyzed. One of the noteworthy characteristics of developing sustainability assessment tools is regional variation. Hence there is a requirement to conduct an industry survey in the construction industry in India to obtain the primary information and data to develop the model. As discussed in Chapter 4, climatic conditions, building materials, methods and technologies, and local conditions influence sustainable assessment tools.

7.3.3 Review details of model development and verification

The different stage divisions in the building development cycle and the three pillars which are associated with each phase are discussed in the literature review. But for further verification to make the model be used for local conditions, an industry survey was conducted. Along with this, assessment indicators are generated from the industry survey to establish the BPS model. An industry survey was conducted to collect data in order to generate the assessment indicators. To gather information and data, a questionnaire survey and semi-structured interviews were conducted.

The results obtained from the survey showed that 73% of the participants said that the green building trend in India has just begun and is developing slowly, and 4.2% of the participants said that the trend has not started yet. About 11.4% of the participants said that it has just started and is developing rapidly, and 11.4% of the participants said that it has entered the developing stage. The reasons for these observations are also analyzed in the study. From the responses of the participants, the main reason for the slow growth of the green building concept in India was a lack of professional awareness, followed by technological constraints, building materials constraints, registration, precertification, and certification fees, and finally the procedures for building assessment. In order to improve the present situation of green buildings in India, various methods can be adopted. For example, introducing legal systems and establishing adaptable assessment systems gained more support in the survey. The results of the survey also show that most of the respondents are not even familiar with any of the assessment tools. Gaps are found between the SATs in India even after considering the literature review and there is a requirement for local SATs. Different building stage divisions and assessment indicators are developed from the questionnaire survey and literature study in order to develop a sustainable BPS assessment model that is suitable for India's situation. Four building phase divisions gained support in the questionnaire and were considered for the assessment, and they were the inception and design, construction, operation, and demolition stages. In addition to this, some indicators to assess building performance were also identified in the survey and literature review. Assessment indicators at every stage in the building life cycle in three pillars were identified and presented in Figure 5.1 in Chapter 5.

After the generation of indicators, an assessment model was developed and verified. This forms the final objective of this research. To evaluate the assessment indicators, both qualitative and quantitative methods are adopted. The BPS is calculated by weighted summation. To understand and identify the importance of one indicator over the other, the AHP method is used. Qualitative and quantitative scores of the indicators are in different units and, hence, to convert them to a common dimension, standardization is applied and these scores are eligible for comparison after standardization.

The BPS model consists of four sub-models to assess the performance at each stage, which comprise environmental, economic, and social scores as well as sustainable scores. BPS represents the overall sustainable performance score. The performance of the building project in all the sustainability pillars at various phases is represented theoretically by this model. Three case studies were considered in the study to verify the model for its efficient applicability in assessing building performances. The BPS for each case study is obtained in all the sustainability pillars at every development project phase. Results of the case studies indicated the advantages and disadvantages of the three pillars at every stage of each case. From the results of the assessment, redesigning and other necessary actions can be considered to achieve sustainable performance before beginning the actual construction.

Results obtained from the BPS model evaluation were compared with LEED scores for further analysis and interpretation. Most of the indicators considered here are quantified and hence fill the gap of fuzziness and uncertainty present in the checklist of previous assessment tools. More comprehensive results are obtained with the combination of qualitative and quantitative indicators for the assessment, and this also supports the opinions of the stakeholders.

7.4 OUTCOME OF BPS MODEL

The BPS model can be used to show the sustainable performance of the building at every stage, including from the inception and design stage to the demolition stage. It is evident from the literature review that various phases of the building development cycle have different sustainable performances. Stakeholders can understand the impacts of various stages when performance is assessed at every stage. Hence, redesigning and other necessary steps can be considered to achieve performance sustainability before beginning the actual construction.

The BPS serves as an opportunity to assess the performance of buildings in environmental, economic, and social aspects. This assessment model is different from previous assessment tools which only focused on environmental aspects, whereas BPS considers economic and social impacts along with environmental aspects. This helps the stakeholders to have a better understanding of when BPS is used to assess the project. Sustainability can be achieved when all three pillars are assessed. The results from the case studies show that sustainability aspects have a varying impact in every development phase of building. Since the BPS model showcases the sustainability performance of buildings at every stage in all three pillars, resources can be paid attention to the stage that has major impacts so as to identify areas of improvement.

7.5 CONTRIBUTION TO KNOWLEDGE

The present study supports a sustainable assessment approach that is different from other approaches and maintains that it is essential to apply sustainable assessment at various phases of building development cycle. Other assessment tools and models provide the overall performance of the building project, whereas BPS provides performance that considers the impacts of sustainability aspects at every phase of the building development cycle. The indicators considered in the BPS model for sustainability are assessed in different ways. Some environmental indicators and economic indicators are quantified in their own units and social indicators are qualified using a VS approach. In this research, both quantitative and qualitative data are combined for the assessment, which helps in obtaining more comprehensive results. Stakeholders' opinions are also considered for the assessment. The concept of sustainability pillars and building development cycle assessment was a 'buzz' word rather than being a real assessment process before the concept of BPS emerged. The BPS model offers a detailed vision regarding the building performance assessment process.

7.6 RESEARCH LIMITATIONS

As discussed in Chapter 1, the building itself forms the boundary conditions for building performance. In order to make buildings accountable for their impacts, these boundary conditions have to be changed. In the present study, boundary conditions considered for performance evaluation are national and the sustainability aspects are evaluated with national scope as the primary consideration. The climatic and economic conditions in India vary from one region to another. An industry survey was conducted and case studies were considered for the study. From the survey, it was found that climatic and economic conditions influence stakeholders' opinions and, therefore, influence the development of model. When applied at the national level or considered in other regions of India, some alterations were required in the model to accommodate the local conditions. The present research focuses on commercial buildings, specifically office buildings. Residential and commercial buildings have an influence on sustainable development and have different features. Residential buildings are found to have less energy consumption and emissions of carbon, but the fact that the number of residential buildings is large cannot be neglected. When a model is considered to assess residential buildings, some adaptations are required to match the conditions.

7.7 RECOMMENDATIONS FOR FURTHER RESEARCH

For further research, and to make the model adaptable for various regions in India, additional modifications can be identified. BPS can be used as a general basis and the assessment indicators in the model can be modified as per the local conditions. Local climatic and economic conditions have a significant influence on the assessment indicators and weightage. More research is required to modify the model in order to meet the local requirements. Different local conditions, which include climatic and economic conditions, and also the cultural background, are considered while developing the assessment indicators in future research. Legal systems and the present green building specifications in India are also used as inputs. A series of BPS models can be developed based on the local conditions, and they act as robust systems for assessment in India. For further research, they also provide a comprehensive database.

Further research in this field will also consider residential buildings for assessment along with other types of buildings. Residential and commercial buildings have an influence on sustainable development and have different features. This research can be used on a general basis and, with additional efforts, an assessment model for residential buildings can be developed.

After developing a model to assess residential buildings and a series of BPS models, a broader concept of the green city can be developed. The scope of the research will be exceeded if municipal planning is considered, which includes transportation and urban facilities. Sustainable concepts with comprehensive assessment should be included in the urban planning stage as one or two sustainable buildings cannot achieve sustainable development. Further effort is required for this research.

Research and development of products for green construction is a vital part of green building promotion. The property of recycling products and facilities is gaining a lot of attention in India. A combination of assessment methodology and sustainable, efficient products can serve to be the best in the construction industry. Some of the SAT's product catalogs are based in their own country. For instance, LEED’s product catalog is based on US local conditions. An adaptability problem arises when this is applied in India. Hence, the development of green construction products for application to local conditions is necessary. Combining the catalog with the sustainable assessment of buildings can fill the gap in the construction industry.

7.8 SUMMARY

This chapter provides a conclusion of the research. Research questions with defined aims and objectives of the study are examined in detail. In this regard, all the set objectives have been accomplished. A BPS model was developed that can assess the sustainability performance of the building by considering the three pillars at every phase of the building development cycle. From the results of the study, improvements can be added at the early stage of the project. Research limitations and the boundary of the study were also discussed. Along with the location, local conditions and different types of buildings and other facilities like transportation in urban planning were also taken into consideration. Therefore, we can conclude that good assessment systems offer decision-makers better insight and assistance to approve and initiate projects.

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APPENDICES

APPENDIX - I: QUESTIONNAIRE SURVEY SAMPLEBUILDING PERFORMANCE ASSESSMENT QUESTIONNAIRE

Dear Sir/Madam,

The Purpose of this research is to develop a model to assess environmental, economicand social performance of building on a life cycle perspective.

You can withdraw from the study at any time and without giving a reason. If you haveany doubts or queries, please feel free to contact

Thanu H P (thanuhp@sjce.ac.in ; +91-9886060622)
Rajasekaran C (bcrajasekaran@gmail.com)
*Required

Part 1: DEATAILS

Name *

____

Email Address*

____

Q 1. How many years have you been in the construction industry?*

☐ Less than 5 years ☐ More than 5 years

Q 2. What is your profession?*

(You can choose more than one option)

☐ Green building consultant ☐ Architect ☐ Cost engineer

☐ Constructor ☐ Structural engineer ☐ Service engineer

☐ Others (Please specify) ---

Part 2: GENERAL QUESTIONS

Q 3. Do you have knowledge regarding performance assessment of green buildings?*

☐ Yes ☐ No

Q 4. Which dimensions do you think should be considered for Building sustainability?*

(You can choose more than one option)

☐ Environmental ☐ Economical

☐ Social ☐ All the above

Q 5. Which tools have you used before for Green Building Rating?*

(You can choose more than one option)

☐ LEED - India ☐ GRIHA ☐ IGBC - India

☐ BEE ☐ Others (Please Specify) ---

Q 6. Compared to western countries, please specify the current situation of green buildings in India.*

☐ Haven't started

☐ Just started and developing slowly

☐ Just started and developing fastly

☐ Almost mature, but still fall behind from developed and other developing countries

Q 7. If you think that India fall behind western countries in green buildings, please choose the possible reason for it and rank them.*

(You can choose more than one option ; Rank 1 = Most Important , Rank 5 = Least important)

☐ Lack of professional awareness ☐

☐ Building materials ☐

☐ Registration, Precertification and certification fees of building assessment ☐

☐ Procedure of building assessment ☐

☐ Technological constraint

☐ Others (Please Specify) ---

Q 8. What idea do you suggest to improve green building in India, rank among the following:*

(You can choose more than one option ; Rank 1 = Most Important , Rank 5 = Least important)

☐ Establish a complete legal system

☐ Develop and use of eco friendly materials

☐ Improve professionals conscious on building sustainability

☐ Others (Please Specify) ---

Part 3: MODEL DEVELOPMENT

Q 9. According to your knowledge, please select the reasonable construction project stages among the following:*

☐ Inception & Design, Construction, Operation and Demolition

☐ Pre-design, Design, Mobilization, Construction and post-construction

☐ Planning, Development, Design, Use, Maintenance and Deconstruction

☐ Raw material extraction, Manufacturing, On-site construction, Operation and End of life or Demolition

Q 10. Do you think all the stages play the equal role in building sustainability?*

☐ Totally the same ☐ Mainly the same ☐ Mostly different ☐ Totally different

Q 11. Please identify the importance of assessing the building performance in every single stage?*

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 13. Please identify the importance of considering the "Construction workers Health and safety" in sustainable building assessment tools in India.*

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 14. Please identify the importance of "Project management" in sustainable building assessment tools to achieve economy and reduce construction waste on site. *

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 15. Please identify the importance of considering the "Topography and climatic factors" in sustainable building assessment tools in India due to varied conditions.*

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 16. Please identify the importance of considering the "Security measures in sustainable building assessment tools to achieve the safety of occupants. *

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 17. To what extent is the "Risk Management", an important factor in the building sustainability assessment?*

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 18. Please identify the importance of considering the "Domestic and solid waste management" in sustainable building assessment tools in India.*

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Q 19. Please identify the importance of considering the "Costs of maintenance and repair" in sustainable building assessment tools in India.*

☐ Extremely important ☐ Very important ☐ Important ☐ Not important

Comments or Suggestions (If any):

APPENDIX - II: VALUE SCORE SURVEY SAMPLE

Please indicate the value score for the qualitative indicators from -2 to +5 according to the levels below.

- $+4 \leq +5$ Best practice (excellent performance)
- $+3 \leq +4$ Very good practice reflecting stable conditions in terms of sustainability
- $1.5 \leq +3$ Good performance
- $0 \leq 1.5$ Current standard (Minimum acceptable standards) or typical practice for particular type of building and region.
- $-2 \leq -1$ Unsatisfactory performance (Deficient) which is not likely to meet the norms and the designed criteria and has negative impacts on the environment in social, economic and environment terms.

Indicators	Criteria	Score
Inception and design stage (Environmental)		
Sustainable Site To maximize the conservation and utilization of resources (land, water, natural habitat, avid fauna and energy) and to enhance efficiency of the systems and operations.	• Green field or brown field • Does it take care of Habitat conservation? To check if the project impact on local flora or fauna and cause damage to the local biodiversity; ➢ Weather it Destroy the vegetation cover ➢ Weather it Destroy the native plant species.	

Heritage conservation Heritage conservation is important for identifying, recording, analysing and protecting heritage and cultural resources of our surroundings.	Does the project site has impact on ancient architecture: • Is there any ancient architecture nearby. • How could the ancient architecture be affected (demolish wholly or partly)	
Sustainable material Encourage the use of building materials to reduce dependence on materials that have associated negative environmental impacts.	Whether sustainable materials are chosen for construction and operation? • Reused or recycled materials • Eco-friendly materials	
Sustainable design Encourage integrated design approach to construct a high performance building, thereby reducing negative environmental impacts.	Whether the design of the project meets the requirement of sustainability • Energy efficient design • HVAC design • Harmless emission, high efficiency, low noise equipment.	

Topography and Climatic condition Awareness about short term weather and long term climate conditions and to appropriately design and successfully manage construction projects.	• Habitat management plan • Conservation of natural habitats • Commissioning and environment management • Temperature conditions (heat rejections, insulation) and orientation of building. • Slope and natural topology. • Execution methodology • Soil and temperature variations	
Inception and design stage (Social)		
Impact on community Incorporation of strategies to create a positive impact on the entire community.	• Provision of good roads and footpaths. • Better Appearance of public area. • Upliftment of employment opportunities to local service providers. • Provide Accessible communication channels with building stakeholders.	
Urban integration The integrated approach to urban development encourages growth and jobs facilities and at the same time promotes a more cohesive society and better environment.	• The attempt to bring betterment in physical, social and environmental conditions in and around the project site i.e, the liveable environment where the project Is planned to build. • The liveable environment include land, soil, the safety appliance installed, aesthetic implication etc.	

Accessibility to public transportation and other facilities Establishing public transport networks that are accessible to pedestrians within a reasonable walking distance.	• Traffic management • Close to essential amenities. • Parking facilities. • Connection to designated green spaces. • Wheel chair access. • Proximity to child minding facilities.	
Cultural issues The act of using deliberate and well-designed methodologies to maintain cultural heritage from the past forthe benefit of thepresent and future generations.	• Recognition of indigenous people through allocation of cultural space. • Consideration of gender equity and minority group requirements. • To preserve traditional &heritage values.	

Construction Stage		
Construction workers health and safety Implementing the right health and safety procedures, providing right knowledge and tools, proper health and safety training.	• Induction to all workers on their rights and responsibilities. • Safety and hygiene of construction workers sheds and dwelling places. • Provision of emergency medical facilities onsite.	

Impact on community Measures to reduce the negative impact and nuisance from construction on the surrounding community.	• Disturbance by construction site. • Public area occupied by the construction process. • Noise and other pollutions • Provision of Employment opportunities.	
Construction Risk Management Measures Proper planning, monitoring and controlling of measures needed to prevent exposure to risk.	• Proper training before construction • Provision of safety jackets • Risk management strategy and plan	

Operation Stage		
Occupants health and comfort Provision of comfort zone to the occupants and meeting all their requirements.	• Sick building syndrome. • The degree of excellence or satisfaction of life quality of building users. • Adequate public liability and service provider insurance. • Awareness of emergency evacuation and first aid procedures.	
Stakeholder relationship Maintaining proper relationship among the stakeholders and ensuring their safety and comfort.	• Keep track of all stakeholder views and concerns. • Transparency regarding the contracts and marketing agreements. • Supportive use and occupation guidelines for tenants. • Proper training for security and public relations personnel.	

Occupants satisfaction and productivity Providing a comfort living space and safety to the occupants.	• Communal service area. • Complimentary usage of building. • Occupant productivity. • Differently abled people access.	
Security measures Incorporating the safety and security measures to ensure the wellbeing of the occupants.	• Hazard prevention measures • Facility access control • Intrusion detection systems • Installation of video and CCTV surveillance technology • Physical and mental wellbeing of the occupants	
Risk management measures Ensuring proper planning for risk mitigation and management.	• Risk assessment and hazard identification. • Effect of environmental stressors on human health and ecosystem.	

Demolition Stage		
Impact on community Avoiding the nuisance to the existing community.	• The views of local communities. • Availability and efficiency of public transport – whether public roads and facilities are disturbed.	
Health and safety Taking proper measures to ensure the wellbeing of the surroundings.	• The health and safety of staff on site and people near the project site. • Risk assessment.	

APPENDIX - III: AHP SURVEY SAMPLE

Please use the scale of 1-9 to define the relative importance of the element A compared to B

1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong or Demonstrated Importance
9	Extreme Importance
2,4,6,8	Intermediate Values

Inception & Design Stage

The lower left hand matrix triangle is reciprocal of upper right hand

A/B	Sustainable site	Sustainable Material	Sustainable Design	Heritage Conservation	Topography and Climatic Condition
Sustainable site	1				
Sustainable Material		1			
Sustainable Design			1		
Heritage Conservation				1	
Topography and Climatic Condition					1

A/B	Land cost	Project Management Consultancy Charges	Other Costs & Charges
Land cost	1		
Project Management Consultancy Charges		1	
Other Costs & Charges			1

A/B	Impact on Community	Urban Integration	Accessibility to publictransport and other facilities	Cultural Issue
Impact on Community	1			
Urban Integration		1		
Accessibility to public transport and other facilities			1	
Cultural Issue				1

Construction Stage

A/B	Energy	Water	Resources	Waste	Noise	Emissions
Energy	1					
Water		1				
Resources			1			
Waste				1		
Noise					1	
Emissions						1

A/B	Construction cost	Project Management Consultancy Charges	Other Costs & Charges
Construction cost	1		
Project Management Consultancy Charges		1	
Other Costs & Charges			1

A/B	Impact on Community	Construction Workers Health and Safety	Construction Risk Management
Impact on Community	1		
Construction Workers Health and Safety		1	
Construction Risk Management			1

Operation Stage

A/B	Energy	Water	Resources	Emissions	Domestic & Solid Waste Management
Energy	1				
Water		1			
Resources			1		
Emissions				1	
Domestic &Solid Waste Management					1

A/B	Operation cost	Maintenance Cost	Occupancy Costs
Operation cost	1		
Maintenance Cost		1	
Occupancy Costs			1

A/B	Occupants' Health & Safety	Stakeholder Relations	Occupier Satisfaction and Productivity	Security Measures	Risk Management Measures
Occupants' Health & Safety	1				
Stakeholder Relations		1			
Occupier Satisfaction and Productivity			1		
Security Measures				1	
Risk Management Measures					1

Demolition Stage

A/B	Waste	Noise	Emissions
Waste	1		
Noise		1	
Emissions			1

A/B	Demolition Cost	Salvage Value	Other Costs & Charges
Demolition Cost	1		
Salvage Value		1	
Other Costs & Charges			1

A/B	Impact on Community	Health and Safety
Impact on Community	1	
Health and Safety		1

APPENDIX – IV: ASSESSMENT INDICATORS IN THE INCEPTION AND DESIGN STAGE

Pillars	Indicators	Criteria	Methods
Environmental	Sustainable site	• Green field or brown field • Does it take care of Habitat conservation? To check if the project impact on local flora or fauna and cause damage to the local biodiversity; Whether it destroy the vegetation cover Whether it destroy the native plant species.	VS
	Sustainable material	Whether sustainable materials are chosen for construction and operation? • Reused or recycled materials • Eco-friendly materials	VS
	Sustainable design	Whether the design of the project meets the requirement of sustainability • Energy efficient design • HVAC design • Harmless emission, high efficiency, low noise equipment.	VS
	Heritage conservation	Does the project site has an impact on ancient architecture: • Is there any ancient architecture nearby? • How could the ancient architecture be affected (demolish wholly or partly)	VS
	Topographic and climatic conditions	• Habitat management plan • Conservation of natural habitats • Commissioning and environment management • Temperature conditions (heat rejections, insulation) and orientation of building. • Slope and natural topology. • Execution methodology • Soil and temperature variations	VS
Economic	Land cost	The cost for the land	LCC
	PMC charges	The consultancy, design and construction plan review fee for the feasibility study	LCC
	Other costs and charges	Other costs include: government charges, rates, taxes	LCC
Social	Impact on community	• Provision of good roads and footpaths. • Better Appearance of public area. • Upliftment of employment opportunities to local service providers. • Provide Accessible communication channels with building stakeholders.	VS
	Accessibility to public transport and other facilities	• Traffic management • Close to essential amenities. • Parking facilities. • Connection to designated green spaces. • Wheelchair access. • Proximity to child minding facilities.	VS
	Urban integration	• The attempt to bring betterment in physical, social and environmental conditions in and around the project site i.e., the livable environment where the project is planned to build. • The livable environment include land, soil, the safety appliance installed, aesthetic implication etc.	VS
	Cultural issue	• Recognition of indigenous people through allocation of cultural space. • Consideration of gender equity and minority group requirements. • To preserve traditional &heritage values.	VS

APPENDIX – V: ASSESSMENT INDICATORS IN THE CONSTRUCTION STAGE

Pillars	Indicators	Criteria	Methods
Environmental	Resource	Construction materials used in the process such as cement, steel, sand, timber, glass etc.	LCA
	Energy	Energy consumed during the construction process such as electricity etc. • Embodied energy • Energy on site	LCA
	Waste	• The amount of waste generated in the construction process • The amount of waste be land filled • The amount of waste can be reused	LCA
	Water	• Water consumption in construction activities • Water consumption by the site workers	LCA
	Emission	The Greenhouse Gas emission during the construction process. • Materials transport to site • Emission when producing construction material • Emission in the construction activities	LCA
	Noise	Noise pollution that occurs during the construction process	LCA
Economic	Construction cost	• Cost for labour • Cost for construction material • Cost for utilities • Cost for equipment (rent, buy) • Financing and services cost	LCC
	PMC charges	The consultant fee for the construction supervision	LCC
	Other costs and charges	• Government charges • Recycling cost • Finance costs • Landfill costs	LCC
Social	Impact on community	• Disturbance by construction site. • Public area occupied by the construction process. • Noise and other pollutions • Provision of Employment opportunities.	VS
	Construction workers health and safety	• Induction to all workers on their rights and responsibilities. • Safety and hygiene of construction workers sheds and dwelling places. • Provision of emergency medical facilities onsite.	VS
	Construction risk and management measures	• Proper training before construction • Provision of safety jackets • Risk management strategy and plan	VS

APPENDIX – VI: ASSESSMENT INDICATORS IN THE OPERATION STAGE

Pillars	Indicators	Criteria	Methods
Environmental	Resource	It refers to the consumption of resources in the operation stage	LCA
	Energy	It refers to the consumption of energy or power in the operation stage	LCA
	Water	• Water for office use • Water for afforestation • Water supply for air conditioner	LCA
	Emission	• Electricity consumption • Consumption of fossil fuels on-site for the production of electricity, hot water, heat, etc. • On-site wastewater treatment • On-site solid wastes treatment • Industrial processes housed in the buildings	LCA
	Domestic and solid waste segregation and management	It refers to the segregation of domestic and solid waste in the operation stage	LCA
Economic	Operation cost	Operational expenses for energy, water, and other utilities.	LCC
	Maintenance cost	The cost incurred for the maintenance of the building	LCC
	Occupancy cost	Occupancy costs are those costs related to occupying a space including: • Rent • Real estate taxes, personal property taxes • Insurance on building and contents • Cost for refurbishment	LCC
Social	Occupants health and safety	• Sick building syndrome. • The degree of excellence or satisfaction of life quality of building users. • Adequate public liability and service provider insurance. • Awareness of emergency evacuation and first aid procedures.	VS
	Occupiers satisfaction and productivity	• Communal service area. • Complimentary usage of building. • Occupant productivity. • Differently abled people access.	VS
	Stakeholder relations	• Keep track of all stakeholder views and concerns. • Transparency regarding the contracts and marketing agreements. • Supportive use and occupation guidelines for tenants. • Proper training for security and public relations personnel.	VS
	Security measures	• Hazard prevention measures • Facility access control • Intrusion detection systems • Installation of video and CCTV surveillance technology • Physical and mental wellbeing of the occupants	VS
	Risk management measures	• Risk assessment and hazard identification. • Effect of environmental stressors on human health and ecosystem.	VS

APPENDIX – VII: ASSESSMENT INDICATORS IN THE DEMOLITION STAGE

Pillars	Indicators	Criteria	Method
Environmental	Waste	Demolition waste is waste debris from destruction of a building. The debris varies from insulation, electrical wiring, rebar, wood, concrete, and bricks	LCA
	Emission	• GHG emissions in the demolition process • GHG emissions in the transportation • GHG emissions inventories from demolition debris reuse, recycling, and disposal activities • Emissions of non-CO2 GHGs in the manufacture	LCA
	Noise	Demolition noise is noise pollution from destruction of a building.	LCA
Economic	Demolition cost	Estimate the demolition cost by buildings' structure • The way of demolition • The features of buildings, like: structure, area, etc. • The amount of debris has to be removed • Labor cost • Cost for equipment rental • Costs for any permits, licenses and insurance policies	LCC
	Salvage value	Salvage value is the estimated resale value of an asset at the end of its useful life.	LCC
	Other costs and charges	Other costs & charges include: government charges, rates and tax	LCC
Social	Impact on community	• The views of local communities. • Availability and efficiency of public transport – whether public roads and facilities are disturbed.	VS
	Health and safety	• The health and safety of staff on site and people near the project site. • Risk assessment.	VS

List of Publications Based on Ph.D. Research Work

Sl. No	Title of the Paper	Authors	Name of the Journal / Conference / Symposium, Vol., No., Pages	Month & Year of Publication	Category*
1	Assessing the life cycle performance of green building projects - A Building Performance Score (BPS) model approach	**Thanu, H. P.,** Rajasekaran, C., & Deepak, M. D.	*Architectural Engineering and Design Management, Taylor and Francis Publishers.* DOI: 10.1080/17452007.2022.2068495	**Accepted for publication**	1
2	Developing a building performance score model for assessing the sustainability of buildings	**Thanu, H. P.,** Rajasekaran, C., & Deepak, M. D.	*Smart and Sustainable Built Environment*, Vol. 11 no. 1, *Emerald publishers* DOI: 10.1108/SASBE-03-2020-0031	September, 2020	1
3	Sustainable Building Management by Using Alternative Materials and Techniques.	**Thanu H.P.,** Kanya Kumari H.G., Rajasekaran C.	*Sustainable Construction and Building Materials. Lecture Notes in Civil Engineering*, Vol 25. https://doi.org/10.1007/978-981-13-3317-0_51.	December, 2018	3
4	Critical study on performance of building assessment tools with respect to Indian context	**Thanu, H. P.,** Rajasekaran, C.	*IOP Conference Series: Materials Science and Engineering*, Vol. 431, p. 082011. doi:10.1088/1757-899X/431/8/082011	October, 2018	1
5	Comparative study on Indian building assessment tools and its limitations	**Thanu, H. P.,** Rajasekaran, C.	*GARI International Journal of Multidisciplinary Research*, Vol 3(2). 1-12.	August, 2017	3
6	Life cycle energy and cost analysis of energy efficient buildings in comparison with conventional building – A case study	**Thanu, H.P.,** Basavangowda S.N., & Rajasekaran, C.	Proceedings of international conference on Advanced Materials & Technology (ICMAT - 16), Mysuru, Karnataka, India.	May, 2016	3

Category*

1 : Journal paper, full paper reviewed
2 : Journal paper, Abstract reviewed
3 : Conference/Symposium paper, full paper reviewed
4 : Conference/Symposium paper, abstract reviewed
5 : Others (including papers in Workshops, NITK Research Bulletins, Short notes etc.)
(If the paper has been accepted for publication but yet to be published, the supporting documents must be attached.)

BIO-DATA

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Employment Details	Working as Assistant Professor, Department Construction Technology and Management JSS STU, Mysuru. (From Sept, 2011 to till date)